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Psychobiology of Altered States of Consciousness

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The article reviews the current knowledge regarding altered states of consciousness (ASC) (a) occurring spontaneously, (b) evoked by physical and physiological stimulation, (c) induced by psychological means, and (d) caused by diseases. The emphasis is laid on psychological and neurobiological approaches. The phenomenological analysis of the multiple ASC resulted in 4 dimensions by which they can be characterized: activation, awareness span, self-awareness, and sensory dynamics. The neurophysiological approach revealed that the different states of consciousness are mainly brought about by a compromised brain structure, transient changes in brain dynamics (disconnectivity), and neurochemical and metabolic processes. Besides these severe alterations, environmental stimuli, mental practices, and techniques of self-control can also temporarily alter brain functioning and conscious experience.

Consciousness has come under renewed scientific investigation, with respect to both the various levels of consciousness and the content of consciousness, through advances in the models and methods of cognitive neuroscience (for a review, see Gazzaniga, 2000; Mesulam, 2000; Zeman, 2001). Everyday conscious awareness is but the tip of an iceberg, underneath which there is a realm

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This work was supported by the Institute for Frontier Areas of Psychology and Mental Health, Freiburg, Germany. The Altered States of Consciousness (ASC) Consortium, founded in 1998, was devoted to the neurophysiological, psychological, and behavioral components of altered states of consciousness. Several psychophysiological laboratories participated in this endeavor and exchanged their results, ideas, and concepts at four consecutive special symposia held in Sils-Maria, Switzerland, from 1999 to 2002.

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of relatively uncharted processes, which are likely to be just as complex as those of so-called altered states of consciousness (ASC), which have tended to defy systematic elucidation; the brain is functionally in a constant state of flux and alteration. There are now attempts to systematically explore, conceptualize, and place these phenomena within the context of neuroscience, which is the subject of this review. We examine advances in understanding the more extreme phenomena traditionally included under the rubric of ASC (Ludwig, 1966) that have accumulated about their neurophysiological, cognitive, and biological underpinnings, together with interrelations between the various domains, including phenomenological analysis. As will be seen, so far the evidence is largely empirical in nature, and there is no overarching model for ASC. However, strategies toward this end are proposed in the Discussion section.

ASC as part of the general experiential and behavioral repertoire have a long history, and ASC were widely accepted earlier when ideas were being explored of consciousness expansion, meditation, LSD, and mystical practices. Myriads of topics were considered but were widely scattered and poorly defined. Several attempts were made to group the seemingly divergent phenomena and to organize their multiplicity. For example, in reviewing the literature on the hypnagogic state, Schacter (1976) showed that the psychological and physiological features characterizing the drowsy interval between waking and sleeping could be elucidated in a descriptive sense. This appeared then to be the only way of synthesizing divergent approaches, given the fact that there were no standard experimental procedures and comprehensive theoretical concepts for the diverse phenomena of ASC that developed and continue to develop in relative isolation. This was exemplified by the anthropological cross-cultural studies of Bourguignon (1966, 1973), which showed that in most cultures there were forms of institutionalized ASC that seemed to emerge from common, basic psychobiological capacities.

The anthropological studies have revealed the ubiquity of and the similarity between phenomena. Recently, a number of theories have argued for common psycho- and neurophysiological processes underlying different ASC such as meditation, trance, and shamanism. Mandell (1980), for instance, postulated hypersynchronous hippocampal–septal (ictal or interictal) activity occurring during microseizures to be the biological bases for ecstatic and mystical states. In the same vein, Persinger (1983) claimed that mystical experiences are associated with transient microseizures in the temporal lobe in nonepileptic individuals. However, it is questionable whether such transient paroxysmal processes can account for the multiplicity and diversity of ASC. In contrast, the present review aims at a broader approach by shedding light on both experiential and neurophysiological diversities of ASC and by mapping the features these various states have in common. Beyond the descriptive approach, explanatory mechanisms are proposed for cases in which the database and empirical evidence are strong enough to be discussed in detail.

In the past, some researchers attempted to identify a common core of subjective changes produced by pharmacological and psychological procedures (Dittrich, von Arx, & Staub, 1985; Ludwig, 1966) or to describe ASC as characteristic patterns of changes on the dimensions of experience ranging from sensation to self-awareness (Farthing, 1992; Pekala, 1991; Tart, 1980). These approaches were mainly based on questionnaires and were helpful in delineating subjectively different ASC. Here it will be seen that the application to ASC of newly developed methods and techniques in cognitive neuroscience, including multichannel electroencephalography (EEG) and magnetoencephalography (MEG), neuroelectric and neuromagnetic source imaging, positron emission tomography (PET), and functional magnetic resonance imaging (fMRI), provide new insights into altered brain functioning.[1]

Apart from focusing on such findings, this review also includes models of neuroscientific approaches to various ASC. The evidential base is mainly devoted to a multilevel approach, including biological, behavioral, cognitive, and subjective domains, with the focus being largely on studies including more than one domain. As shown in Table 1, altered states can be classified by their origin, that is, spontaneous, induced, or pathological. In the table some irreversible pathological conditions have been included, although some authors restrict the term *ASC* to reversible, short-term conditions only (Farthing, 1992). The multitude and heterogeneity of states induced by pharmacological agents was not included here. These states are not considered to be unimportant—to the contrary; however, the members of the ASC Consortium focused their research mainly on clinical conditions or physiological and psychological induction methods, which represent a broad field to be reviewed all by themselves (for recent reviews of pharmacological-induced ASC and affected neurotransmitter systems, see Aghajanian & Marek, 1999; Parrott, 2001; Snyder, 1996; Vollenweider & Geyer, 2001). The classification provided in Table 1 has been used to structure our review.

Spontaneously Occurring ASC

During daily activities, spontaneous fluctuations in wakefulness, alertness, and vigilance occur. They are subjectively experienced as being part of phenomenal awareness, which oscillates on the wakefulness–drowsiness–sleep onset continuum. Four major classes of spontaneously occurring ASC are addressed here: states of drowsiness, daydreaming, hypnagogic states, and sleep and dreaming. Among the spontaneously occurring ASC, near-death experiences are an infrequent and peculiar class of phenomena, detailed later in this section.

States of Drowsiness

Variations of vigilance within the normal sleep–wake cycle usually do not induce ASC. Alterations of consciousness may

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[1] Only EEG and MEG allow for the time resolution to observe online changes of mental processes, both reflecting summation of synchronized synaptic inflow to apical dendrites of the cortex. Whereas EEG originates from vertically oriented pyramidal cell columns, MEG reflects tangential electromagnetic dipoles mainly located in the cortical sulci. Spatial resolution of EEG and MEG approaches 2 mm under special conditions (such as early evoked sensory potentials and fields; for a review on EEG, see Rockstroh, Elbert, Canavan, & Birbaumer, 1989). Subcortical activity can be visualized only with blood-flow-metabolic measures such as PET and fMRI. Time resolution of both is in the order of seconds; spatial resolution is in the order of millimeters. Both record the increases or decreases of blood flow as a consequence of neural activity, particularly local dendritic field potentials (Logothetis, Pauls, Augath, Trinath, & Oeltermann, 2001). PET, through the injection of radioactive ligands, allows specification of local accumulation of several metabolic products, such as glucose, dopamine, fluoride, phosphor, opiates, and others (for an overview of brain imaging, see Toga & Mazziotta, 2000).

Table 1
Domains Associated With Alterations of Consciousness Classified by Their Origin or Method of Induction

Origin	Alteration
Spontaneously occurring	States of drowsiness
	Daydreaming
	Hypnagogic states
	Sleep and dreaming
	Near-death experiences
Physically and physiologically induced	Extreme environmental conditions (pressure, temperature)
	Starvation and diet
	Sexual activity and orgasm
	Respiratory maneuvers
Psychologically induced	Sensory deprivation, homogenization, and overload
	Rhythm-induced trance (drumming and dancing)
	Relaxation
	Meditation
	Hypnosis
	Biofeedback
Disease induced	Psychotic disorders
	Coma and vegetative state
	Epilepsy
Pharmacologically induced	(Not reviewed)

occur with extreme sleep deprivation, resulting in short episodes of immediate sleep onset (microsleep; Oswald, 1962) or amnesic automatic behavior (Guilleminault, Billard, Montplaisir, & Dement, 1972). Subjective experience features narrowed attention, reduced volitional potential and motivation, decrease of memory, and impaired cognition. Time awareness may be significantly affected: Wackermann, Pütz, and Miener (2001) found verbal overestimates of elapsed time intervals (1–40 min). Behavioral correlates of drowsiness and sleepiness comprise performance decrements in psychomotor tasks, particularly response omissions, and increased reaction times in stimulus detection or discrimination tasks. As for physiological correlates, various parameters have been used to study fluctuations of vigilance and drowsiness (e.g., EEG, electrooculography, autonomic measures). Changes include a shift of EEG spectra to slower frequencies (Davis, Davis, Loomis, Harvey, & Hobart, 1937); reduced latency/amplitude of event related potentials (P300; Harsh, 1994); slow eye movements, disappearance of saccades, and reduced "blinks" (Matousek, & Petersén, 1979); and an increase in pupil diameter variability (Lavie, 1979; Lowenstein & Loewenfeld, 1964). Established objective EEG-based vigilance measures include mostly EEG spectral measures and indices (Herrmann, Kubicki, & Röhmel, 1988; Jung, Makeig, Stensmo, & Sejnowski, 1997; Makeig & Inlow, 1993; Matejcek, 1982; Matousek & Petersén, 1983; Stampi, Stone, & Michimori, 1993); global brain state descriptors based on multichannel EEG have also been used (Wackermann, 1999). For a comprehensive discussion of objective and subjective measures to assess sleepiness, see Curcio, Casagrande, and Bertini (2001). Assessment and classification of states of drowsiness is difficult owing to varying concepts like activation continuum (Lindsley, 1960), wakefulness, alertness, vigilance (Head, 1923; cf. Davies & Tune, 1970; Ulrich & Gschwilm, 1988; Weinberg & Harper, 1993), and sleepiness and drowsiness. Drowsiness states open ways to so-called hypnagogic states at sleep onset, which are treated below as a special, stand-alone class of ASC.

Daydreaming

Daydreaming refers to spontaneous, subjective experiences in a no-task, no-stimulus, no-response situation (see also the sections on hypnagogic states and sensory deprivation). Daydreaming also includes unintended thoughts that intrude inadvertently into the execution of intended mental tasks (Uleman & Bargh, 1989) and undirected ideas in thought sampling during wakefulness (Klinger, 1978). Daydreaming clearly differs from reality-focusing mentation, and several characteristics of daydreaming strongly differ from those of rapid eye movement (REM) dreams; for example, daydreaming showed a 100% increase of familiar settings and an about 20% increase in emotional involvement (Strauch & Meier, 1996). Implicitly, daydreaming, when juxtaposed with night dreaming, seems to imply waking in contrast to sleep, although the nature of daydreaming's position on a vigilance scale remains a subject of daydreaming studies. Much of the present daydreaming literature concerns therapeutic applications of Freud's free-association technique, the proposed royal road to the unconscious (Freud, 1900). Another large part of this literature originates from James's (1890) "stream of thought" concept and predominantly reports phenomenology, taxonomy, and psychological and social conditions of daydreaming (Giambra, 1999–2000; Pope & Singer, 1978).

Neurophysiological studies on daydreaming are rare. Cunningham, Scerbo, and Freeman (2000) reported that there were EEG power spectral signs of lowered vigilance prior to daydreaming being signaled by the subjects. A study on subjective experiences during daydreaming conditions and EEG power spectra revealed correlations between distinctive features in EEG spectra and cognition styles (Lehmann, Grass, & Meier, 1995). One hundred twenty EEG spectral (power) variables and 20 cognition or emotion variables resulted in four significantly different, independent pairs of canonical variables: Pair 1 had prominent 2–6 Hz and (left) 13–15 Hz EEG power with reality-remote, sudden undirected ideas of low recall quality; Pair 2 had lowered 10–13 Hz and 15–25 Hz and (medial right) increased 4–6 Hz power, with sudden undirected ideas but with good recall and visual imagery yet without emotion. These two pairs belong to the hypnagogic family, whereas the remaining pairs were of the awake type: Pair 3 had 10–11 Hz and 19–30 Hz power, with goal-oriented, concatenated thoughts related to the present and future, with little emotion; Pair 4 had a power profile roughly inverted to Pair 2, with reality- and future-oriented thoughts and positive emotion.

Another study showed that EEG power spectral characteristics during a daydreaming condition were close to characteristics in ganzfeld conditions (see section on sensory homogenization) but differed from those during sleep onset (Wackermann, Pütz, Büchi, Strauch, & Lehmann, 2002). These studies examined relatively long EEG epochs of 16 s and 30 s; however, the basic units of mentation processes were estimated to be well in the subsecond time range (around 100 ms; Newell, 1992). Microstate analysis of EEG data offers resolution in this time range and has found that the human brain electric state is quasi-stable for fractions of seconds, then rapidly reorganizes into another state, so that brain activity can be parsed into sequences of quasi-homogeneous temporal segments (microstates). Different classes of thoughts in a daydreaming condition were found to belong to different classes of microstates of about 120 ms duration (Lehmann, Strik, Henggeler, Koenig, & Koukkou, 1998). Whether there are microstate classes specific for daydreaming still needs to be investigated. In sum, the seemingly continual stream of consciousness is discontinuous, consisting of a sequence of concatenated, psychophysiological building blocks (“atoms of thought”; Lehmann et al., 1998) that follow each other in fractions of seconds and whose functional significance is identifiable as classes of subjective experiences. Further microstate analyses are needed to identify the psychophysiological building blocks of daydreaming and their syntax, that is, their rules of concatenations.

Hypnagogic States

Hypnagogic states are transient states of decreased wakefulness characterized by short episodes of dreamlike sensory experience. These phenomena were first described by J. Müller (1826/1967) as “fantastic visual phenomena” (p. 20ff) occurring usually, but not exclusively, at sleep onset. Maury (1848) coined for them the term *hypnagogic,* from Greek *hypnos* (sleep) and *agogo* (I bring). Schacter (1976) described them as “dreamlets.” Subjects usually report short visual percepts like faces, landscapes, and natural or social scenes that may or may not be related to previous daytime experience. These percepts may be of pseudohallucinatory (i.e., with preserved insight of unreality) or truly hallucinatory (i.e., experienced as if real) character. In contrast to dreams, hypnagogic experiences are usually rather static, without narrative content, and the subject is not involved as an actor (cf. *Sleep and Dreaming* section). Hypnagogic states have been extensively studied for their peculiar phenomenology (Leaning, 1925; Leroy, 1933; Linschoten, 1955) and symbolic character (Silberer, 1909). Hori, Hayashi, and Morikawa (1994) conceived of hypnagogic states as a unique period that cannot be accurately categorized as either waking or sleeping, and with unique behavioral, electrophysiological, and subjective characteristics. Similar phenomena occurring at the transition from sleep to wakefulness are called *hypnopompic* (Myers, 1904); here, however, it is difficult to differentiate hypnagogic imagery from remnants of dream imagery. Hypnagogic-like phenomena may also occur in daytime periods of reduced wakefulness and possibly superimposed over adequate sensory perceptions of the environment (cf. Mavromatis, 1987; Schacter, 1976; Sherwood, 2002). Subjective experience in hypnagogic states comprises vivid, mostly very brief episodes of usually visual (86%) and acoustical (8%) imagery with other sensory modalities occurring less frequently and with an average recall rate of 35%. There is more awareness of the real situation in hypnagogic states than in dreaming (Hori et al., 1994). The prevalence for frequent hypnagogic states is estimated at 37% (Ohayon, Priest, Caulet, & Guilleminault, 1996). Behavioral correlates are sparse, for example, leg or arm jerks (“sleep starts”) associated with illusionary body movements (American Sleep Disorders Association, 1990; Sherwood, 2002). As for physiological correlates, an association between short flashes of dreamlike imagery and drop-offs in alpha EEG activity was first noticed by Davis et al. (1937). By definition, hypnagogic states are related to sleep onset, that is, Sleep Stage 1 according to Rechtschaffen and Kales (1968), but may occur even with presleep alpha EEG (Foulkes & Schmidt, 1983; Foulkes & Vogel, 1965). Kuhlo and Lehmann (1964) studied hypnagogic states and their EEG correlates during drowsiness and sleep onset: Spontaneous, transient, fragmentary nonemotional visual and auditory impressions of varying complexity were reported that were mostly experienced as unreal and were associated with flattened or decelerated alpha and/or slow theta EEG activity; the authors postulated a gradual progression from hypnagogic hallucinations to fragmentary dreams (cf. Lehmann et al., 1995). Systematic comparisons of hypnagogic phenomena with perceptual phenomena that were observed with reduced sensory input (cf. section on sensory homogenization and “ganzfeld”) led us to conceptualize a broader class of “hypnagoid” phenomena (Wackermann, Pütz, Büchi, Strauch, & Lehmann, 2000, 2002), of which the true hypnagogic hallucinations are a special case, and in spite of distinctly different brain functional states at sleep onset and in ganzfeld, subjective experience exhibits very similar features.

Sleep and Dreaming

Dreaming, which is not restricted to REM sleep but has been found to take place in all sleep stages, represents an ASC, characterized by a virtual sense of reality, a wide range of primarily visual perceptions, covert speech, motor activities, emotions, and social interactions. Typical of dreams are a narrative structure and elaborations, ranging from the realistic to the fantastic. However, parallel cognitive processing and metacognition are reduced, while the emphasis is on the here and now. A virtual sense of reality (except for the rare category of lucid dreams, discussed below) and a predominant ego involvement are the only continuous features of dreaming; all of the other features are more or less phasic events (Strauch & Meier, 1996).

Since the discovery of REM sleep by Aserinsky and Kleitman in 1953, in the majority of dream research studies, physiological recordings have been primarily used to determine sleep stages and the appropriate time to awaken a subject. By collecting reports under such stage-controlled conditions, the general phenomenology of dreaming has been exhaustively examined, ranging from night terrors to lucid dreams. From the outset, the association between various physiological signals and quality of dream content has been investigated on different levels, with intent to validate the subjective experiences (Arkin, Antrobus, & Ellman, 1978).

At the sleep-stage level, dreams from REM and non-REM states, although discriminable on average (Monroe, Rechtschaffen, Foulkes, & Jensen, 1965), have proved to differ primarily in rates of recall and extent, with REM dreams being better recalled and being longer (Antrobus, 1983). Given comparable lengths, variations between sleep stages were a less significant factor (Foulkes & Schmidt, 1983). Dreams outside of REM can be as bizarre and emotional as REM dreams, and REM dreams can be as mundane and bland as dreams from other stages (Strauch & Meier, 1996).

More specifically, physiological variables have been selected by apparent face validity. The *scanning hypothesis,* implying that incidence and directional changes of eye movements during REM sleep are related to the dreamer’s viewing pattern (Ladd, 1892), first yielded promising results (Roffwarg, Dement, Muzio, & Fisher, 1962), but these could not be replicated (L. Jacobs, Feldman, & Bender, 1972). Weak associations were also found between on–off eye movements versus visualization and cognitive elaboration (Foulkes & Pope, 1973). Furthermore, little correspondence has existed between phasic muscle activation in arms and legs and dreamed motor activity (R. Gardner, Grossman, Roffwarg, & Weiner, 1975), between middle ear muscle activity and auditory perceptions (Pessah & Roffwarg, 1972), between speech muscle activation and verbal activity (Shimizu & Inoue, 1986), and between phasic bursts of the facial corrugator and zygomatic muscles and emotions (Gerne & Strauch, 1985).

In the majority of spontaneous dreams, self-reflection and control of the dream are only moderately present (Purcell, Moffitt, & Hoffmann, 1993). Lucidity during REM sleep—when not associated with microawakenings—represents a rather rare and exceptional category of dreaming, whereby the dreamer is aware of the dream and capable of influencing dream events. Selected subjects can be taught to bring such experiences about more frequently and to signal onset of lucidity, for example, by intentional eye movements. Such prearranged signals, executed and recorded during REM sleep, allow the further investigation of experiential–physiological parallelism (LaBerge, 2000).

Recently, Foulkes (1996) reviewed 40 years of dream research. He came to the conclusion that the results of psychophysiological studies on the whole have tended to be weak and unreplicable and that "the bloom definitely was off the psychophysiological association by 1980" (Foulkes, 1996, p. 613).

A more basic quest for the locations of the generators of dreaming is of current interest. Murri, Arena, Siciliano, Mazzotta, and Muratorio (1984) reported frequent loss of dream recall after unilateral posterior lesions but rarely after anterior lesions. Solms (1997) observed that patients with bilateral lesions in the occipitotemporal region had no visual dreams and that posterior cortical or bilateral frontal lesions were associated with a global cessation of dreaming. He has claimed that the forebrain is a common path to dreaming, whereas Hobson maintains that dreaming is "a result of the excitation of forebrain circuits by impulses arising in the ascending activation systems of the brain stem . . . and basal forebrain" (Hobson, 1999, p. 171). Present imaging techniques (e.g., PET) during REM have yielded different results: activation of extrastriate visual cortices, attenuation of primary visual cortices, activation of limbic and paralimbic regions, and attenuation of frontal association areas (Braun et al., 1998). A detailed discussion of the psychophysiology of sleeping and dreaming research was recently published in *Behavioral and Brain Sciences* (Harnad, 2000). Up to now, no coherent model of the neural underpinnings of dreaming has been evolved that integrates the findings from lesion and imaging studies. At best, these different approaches may further clarify which brain areas are specifically activated during various sleep stages; however, they will not be able to decode the content of dreaming.

The results of numerous studies undertaken to relate the experience of dreaming to accompanying bodily processes have so far proved to be modest, if not discouraging. Psychophysiological dream research is faced with the insoluble problem that dreaming cannot be reported online but only retrospectively while one is awake. Owing to the functional state shifts involved in dreaming and recall (Koukkou & Lehmann, 1983), a subject's ability to recall a dream may be incomplete or totally inhibited. Furthermore, the conversion of a dream experience into a verbal report may go along with transpositions and omissions, which makes it more difficult to reliably assign at a given moment a physiological signal to a psychological event. Therefore, as far as the altered state of dreaming is concerned, the wide gap between physiology and psychology still has to be bridged.

Near-Death Experiences

The typical core elements of near-death experiences include (a) a feeling of peacefulness and well-being, (b) a separation from the body (out-of-body experience), (c) a dark tunnel experience, (d) a brilliant light associated with mystical feelings of love and union, and (e) a heavenly landscape (often relatives, religious figures, or beings of light appear and finally initiate the return to the body). Other elements are the hearing of music, a slowing of time and speeding of thoughts, and a panoramic life review. The incidence of near-death experiences is estimated to lie between 10% and 50% of all near-death situations and is independent of gender, age, and profession (Schroeter-Kunhardt, 1993). The circumstances of the close brush with death (e.g., from illness, accident, suicide, or anesthetics) have only a minor influence on the occurrence and features of the near-death experiences (Greyson, 2000). This invariance suggests a specific neurophysiological mechanism taking place in the dying brain. Accordingly, several hypotheses have been formulated regarding the neurophysiological processes (cerebral anoxia, depletion of neurotransmitter reservoirs, release of endorphins, general disinhibition of the brain) and structures (limbic system, septohippocampal formation, temporal lobes, visual cortex) that have been involved in the generation of near-death experiences (Blackmore, 1996; Morse, Venecia, & Milstein, 1989; Saavedra-Aguilar & Gomez-Jeria, 1989). Because no experiments can be performed to induce real near-death experiences, the neurophysiological explanatory models are mainly based on speculations and analogue experiments that produce ASC with features similar to those observed during near-death experiences, such as a body acceleration reducing the cerebral blood supply until a loss of consciousness occurs (Whinery, 1997); the administration of drugs, like ketamine (Jansen, 1997); or the electromagnetic stimulation of the temporal lobes (Persinger, 1999). After a critical evaluation of these approaches Greyson (2000) concluded that no single approach is able to account for all of the features of near-death experiences. Nevertheless, the study of those elements that occur in many conditions, like the out-of-body experience, improves the prospects of elucidating the brain mechanisms underlying the entire sequence of events.

Conclusions

The bulk of evidence on ASC whenever they occur spontaneously supports changes in cortical activity and arousal levels. They are subjectively experienced as dreamlike, illusionary, and hallucinatory and, in many cases, are quite deviant from normal alert, waking, and vigilant states. These changes are transient in nature and immediately vanish when the central arousal system returns to normal levels either by voluntary control, biological rhythms (sleep–wake cycles), or resuscitation.

Physically and Physiologically Induced ASC

Besides pharmacological induction, a wide variety of physical and physiological methods and maneuvers may result in alterations of consciousness or even lead to short- or long-term loss of consciousness. One pivotal class of circumstances or situations under which these detrimental effects have been observed includes extreme environmental conditions and starvation. In contrast to these possibly life-threatening environmental and behavioral conditions, there are other physiological conditions that may result in ASC, such as sexual activity and orgasm, described by the French expression *la petite mort,* and forced respiratory maneuvers.

Extreme Environmental Conditions

Behaving in extreme environments has been reported anecdotally to induce ASC, including auditory or visual hallucinations, somesthetic illusions, or states of trance. However, although most of these reports have captured large public interest (i.e., Messner, 2001), little systematic research is available on the effects of such environments on states of consciousness.

Research on psychological effects of extreme environmental conditions covers a broad range of life-threatening environments. Conditions explored include exposure to high altitudes in mountaineers of Himalayan expeditions, hyperbaric underwater conditions on divers, low temperature conditions on members of Arctic and Antarctic research groups, extensive heat on extreme athletes bicycling or walking through desserts, and exposure to microgravity during space flights.

In one of the few empirical studies (Brugger, Regard, Landis, & Oelz, 1999), the incidence and the circumstances of ASC were investigated retrospectively by structured interview on the effects of exposure to altitudes above 8,500 m without supplementary oxygen in eight world-class climbers. Additionally, subjects were examined by neuropsychological tests and electroencephalographic and MRI techniques within a week following the interview. All but one of the mountaineers reported distortions of the body schema to be the major type of somesthetic experience followed by visual and auditory hallucinations. These illusions and hallucinations were reported more frequently at altitudes above than below 6,000 m. Hallucinations and illusions were not related to brain abnormalities and were suggested to be consequences of severe hypoxia and social deprivation and acute stress conditions experienced during mountaineering. The majority of studies on the negative effects of exposure to extremely high altitudes on cognitive, emotional, and behavioral functioning so far suggest that visual and auditory illusions or hallucinations seem mainly to be caused by the development of severe hypoxia and acute mountain sickness in those subjects who did not adjust properly prior to exposure to high altitudes or who stayed at extreme heights for too long a period (Hackett & Roach, 2001).

Although similar anecdotal reports on the emergence of illusions, hallucinations, cognitive dysfunctions, and negative emotional states exist for professional and experienced scuba divers (Chowdhury, 2000), no systematic research is available on what incidence, types, and circumstances of exposure to hyperbaric conditions are associated with the emergence of ASC or different cognitive and behavioral dysfunctions. Although some experimental studies in simulated hyperbaric conditions reported decrements in attention, memory, vision, audition, and sensation (Charles, Allimann, & Ragot, 2001; Massion, Fabre, Mouchnino, & Obadia, 1995), a number of studies did not (Abraini et al., 1997; Bast-Pettersen, 1999). The emergence of ASC or different cognitive and behavioral dysfunctions is supposed more likely to be related to present paroxysmal symptoms resulting from individual narcotic potencies of gases contained in the breathing mixtures (Abraini, 1995) inhaled by divers while being in deep water for long periods of time (Tetzlaff et al., 1999).

There is also no systematic study available on the effects of prolonged heat exposure in extreme athletes walking or bicycling through desserts.

Overwintering in Arctic or Antarctic environments is a common strategy for investigating the effects of extreme environments on psychological and physiological adaptation, performance, and well-being. Although reports of hallucinations, sensory illusions, and hypnotic states have also been presented for these environments, systematic research is missing. From some studies of cognitive and behavioral dysfunctions (Bhargava, Mukerji, & Sachdeva, 2000; Brennen, Martinussen, Hansen, & Hjemdal, 1999) and emotional disorders (Haggarty, Cernovsky, Kermeen, & Merskey, 2000), it can be inferred that most ASC are strongly associated with the emergence of different diseases and illnesses (e.g., shining, cottage fever, infectious diseases, brain injuries) or with acute stress following interpersonal conflicts between group members (Kahn & Leon, 1994; Palinkas, 1992; Wood, Lugg, Hysong, & Harm, 1999). Additionally, such states might be possible consequences of sudden failures of life-supporting technical equipment being perceived as extreme stress conditions (Palinkas, Gunderson, Johnson, & Holland, 2000).

Despite some evidence that prolonged exposure to microgravity might affect cognitive functioning and motor behavior in negative ways (Brubakk, 2000; Fowler, Comfort, & Bock, 2000; Friederici & Levelt, 1990; Manzey & Lorenz, 1999), no systematic studies are available indicating that hallucinations, sensory illusions, or other subtypes of ASC are common phenomena of cosmonauts or astronauts (Carr, 1991) during spaceflights. Again, it is assumed that such responses are paroxysmal consequences of primary diseases or of sudden illnesses (Dudley Rowley, 1997).

Starvation and Diet

Starvation and extreme diet are accompanied by a number of (patho)physiological alterations and are associated with cognitive, social, emotional, attentional, and behavioral changes (e.g., Maddox & Long, 1999; Peterson & Mitchell, 1999). In strong dieters as well as in anorectic patients, extreme starvation and diet might induce ASC, as expressed by an attentional bias for food stimuli, disturbed body image, illusions, or hallucinations.

On the basis of studies using a modified version of the Stroop test, short-term diet was shown not to be associated with an attentional bias. In this test, subjects were requested to name the color of words belonging to different categories (food and body image vs. neutral in relation to these categories) but not to attend to the content. It was found that extreme dieters and anorectic patients show increased reaction times to food-related words not observed in normal subjects or fasting persons (e.g., Ben-Tovim & Walker, 1991; Huon & Brown, 1996). Additionally, anorectics but not dieters or controls responded with increased reaction times to words related to body image.

Data belonging to the scope of the review are often available only for anorectic patients, that is, for starvation in its pathological version. Starvation in anorectic patients was demonstrated to be associated with decreased regional cerebral blood flow in the right hemisphere that normalized after weight gain (Delvenne et al., 1996, 1997). Additionally, it was shown that early and late components of evoked potentials to somatosensory stimulation were decreased (e.g., Lautenbacher, Pauls, Strian, Pirke, & Krieg, 1991) and that spectral power of EEG background activity was reduced in the alpha-1 band in strong dieters and anorectic patients, but also there was decreased theta EEG power over the right parietal cortex during haptic exploration tasks that remained still modified after weight gain (Grunwald et al., 2001).

In summary, there exists some evidence for an attentional bias to food in extreme dieters that seems to be accompanied by changes in regional cerebral blood flow and EEG power. However, further research is needed to clarify the basis of these alterations.

Sexual Activity and Orgasm

In several studies over the past 50 years, various changes in the electrical activity of the brain during sexual arousal and orgasm have been described. Mosovich and Tallaferro (1954) reported rapid low-voltage activity during early stages of sexual arousal that was followed by slow high-voltage paroxysmal activity during orgasm. Heath (1972) recorded subcortical and cortical EEG with implanted electrodes in two patients and found slow wave and spike activity with interspersed fast activity mainly in the septal region during orgasm. These waveforms matched paroxysmal discharges in epilepsy. H. D. Cohen, Rosen, and Goldstein (1976) showed that alpha waves in both hemispheres during baseline give way to high-amplitude 4-Hz activity over the right parietal lobe during orgasm, which was not visible during a "faked orgasm." This interhemispheric asymmetry was confirmed by Tucker and Dawson (1984). They found less alpha power and higher coherence in central and posterior regions of the right compared with the left hemisphere during sexual arousal induced by imagery. The results were replicated by A. S. Cohen, Rosen, and Goldstein (1985) with erotic films. Flor-Henry (1980) stated that in epilepsy patients with seizures leading to orgasm, the orgasmic response was triggered by discharges in the right hemisphere. In contrast to the described profound changes in the EEG, Graber, Rohrbaugh, Newlin, Varner, and Ellingson (1985) found only a small decrease in alpha activity during masturbation and ejaculation.

Tiihonen et al. (1994) confirmed the results of lateralized right hemispheric activation during orgasm with single positron emission computed tomography. They found increased regional cerebral blood flow at the right prefrontal cortex.

Neurosurgery and brain lesions after injury have revealed the involvement of frontal and temporal areas in the inhibitory control of sexual behavior (Freeman, 1973; Terzian & Dalle Ore, 1955) and septal nuclei in the control of sexual arousal (Gorman & Cummings, 1992). Redouté et al. (2000) presented their male subjects with visual sexual stimuli in the PET scanner. They found a highly significant bilateral increase of regional cerebral blood flow in the claustrum and putamen, which was positively correlated with perceived sexual arousal. Another activated region was the nucleus accumbens and the rostral part of the anterior cingulate gyrus. The nucleus accumbens serves as the common final endpath of the dopamine incentive system and therefore plays an unspecific role in the organization of sexual responses (see Rolls, 1999). The magnitude of activation of the latter correlated strongly with penile tumescence. Stimulation of this region leads to erection in monkeys (Dua & MacLean, 1964). Likewise, Rauch et al. (1999) found activation in the rostral region of the anterior cingulate gyrus during sexual and competitive arousal. In contrast, activity in temporal lobes decreased during an increase of sexual arousal (Redouté et al., 2000).

To summarize, subcortical paroxysmal and right hemispheric high-amplitude slow activity appear to be related to the partial loss of consciousness during orgasm. Along with sexual arousal and orgasm, a lateralized right hemispheric activation occurs. These modifications of the EEG clearly classify orgasm as a specific ASC not comparable to any other psychophysiological states.

Respiratory Maneuvers

Among methods of inducing ASC, changes in breathing patterns are of significant interest. Most breath manipulations are based primarily on Yoga and Zen practices, and they include passive breath mindfulness and breathing (Lichstein, 1988). This requires the trainee to focus attention on breathing and allows slow and shallow respiration to emerge. In meditation techniques, breath manipulation works with mantra chanting, counting, and maintaining a fixed gaze on an external object or cue word. Deep breathing consists of taking a deep breath, retaining the breath, and exhaling slowly. The method of slow diaphragmatic breathing and paced respiration is also a procedure that alone or in combination with other meditative techniques leads to tension reduction in body musculature and to the balance of neurovegetative regulatory systems. The mechanisms of these breathing techniques are based on increases in pCO_2, resulting in hypercapnia. Breath holding (for 5–10 s) and shallow, slow breathing producing hypoventilation are two methods with which to create mild hypercapnia including a slow heart rate, dilation of the peripheral vasculature, stimulation of gastric secretion, depressed cortical activity, and a global sensation of mild somnolence (Lichstein, 1988). This normally occurs in the transition from wakefulness to drowsiness, in hypnagogic states, and in sound sleep (Naifeh, Kamiya, & Sweet, 1982).

Similar hypercapnia effects can also be evoked by inhaling a CO_2-enriched breathing air mixture. Meduna (1950) reported that hypercapnia may result in typical near-death experiences, such as bodily detachment and the perception of being drawn toward a bright light. Both phenomena were associated with power increases in EEG low-frequency bands. A recent study by Terekhin (1996), however, failed to confirm these findings. Here a CO_2-enriched breathing air mixture did not lead to slow-wave EEG and concomitant experiences of obnubilation, depersonalization, and derealization. These differences may largely be traced back to the varying amount and duration of inhaling a CO_2-enriched air mixture.

Breathing has also been manipulated by techniques that lead to hypocapnia, such as shamanism practices, ritual dances, holotropic breathing (Grof, 1976), and rebirthing. In this context, breathing plays a pivotal role. Involuntary hyperventilation often accompanies hard physical work, long-lasting emotional tension, and enduring mental effort. Hyperventilation is also involved in panic attacks and their clinical symptoms (e.g., dyspnea, vertigo, palpitations, chest pain, numbness or tingling, depersonalization, fear of losing control; W. N. Gardner, 1996). When healthy subjects were required to voluntarily hyperventilate, 83% experienced syncopes marked by an incipient fall (Lempert, Bauer, & Schmidt, 1994). Arrhythmical mycloni occurred in 90% of 42 syncopal episodes. Visual (e.g., colored patches, bright lights, gray haze) and auditory (e.g., roaring noises, screaming) hallucinations were reported by 60%. Commonly, subjects described a state of impaired external awareness, disorientation, weightlessness, detachment, and loss of voluntary motor control.

Forced respiration during hyperventilation has rapid and far-ranging physiological effects via its alteration of pH and depletion of CO_2 in the body, resulting in acute or chronic respiratory alkalosis (hypocapnia). The cerebral circulation is highly sensitive to respiratory alkalosis, which develops within the first 15–20 s of hyperventilation. As a consequence, pronounced hypocapnia ($PaCO_2$/22 mmHg or less) affects regional and local cerebral hemodynamics, circulation, and oxygen supply. Hyperventilation-induced changes in EEG (slow waves in the frontal leads, hypersynchronization) were found to be identical to the hypoxia-induced changes, such as arteriole vasospasm, ischemic foci, and redistribution of the blood flow between various brain regions (Paulson & Sharbrough, 1974). In both cases, fainting, obnubilation, depersonalization, and similar forms of ASC may occur.

The interaction between respiratory maneuvers, such as hyperventilation and alteration of consciousness, can also be considered under clinical perspectives. Hyperventilation represents a well-established EEG activation procedure aimed at enhancing epileptiform discharges, which may result in impairment of consciousness (absence). Typical ictal absences have been precipitated by hyperventilation in about 90% of untreated patients (Panayiotopoulos, 2001).

Independent of respiration-induced hyper- and hypocapnia, there is another, more gentle respiratory maneuver that is an important constituent of yogic (Pranayama) breathing exercises—that is, unilateral nostril breathing, where the airflow is forced through each nostril in turn. Stancak, Hönig, Wackermann, Lepicovska, and Dostalek (1991) studied young subjects during bilateral and 15 min of unilateral nostril breathing. Besides cardiovascular changes (e.g., increased respiratory sinus arrhythmia), they observed lowered peak power of beta-2 EEG activity in the frontal leads during unilateral nostril breathing, indicating a relaxation-specific effect, as found in the study by G. D. Jacobs, Benson, and Friedman (1996). In addition, they found a homolateral relationship between the nostril airflow and EEG theta activity, which they attributed to a lateralized modulation of the subcortical generators of EEG theta-band during unilateral nostril breathing.

The similarity of electrocortical brain functions during hyperventilation and ASC is somewhat striking, although their origins may largely vary (for discussion, see Schwartz, 1995). Generally, this suggests that ASC-like phenomena can be evoked by changes in the respiratory pattern and that they share common basic mechanisms of respiratory–circulatory–electrocortical interaction (Grossman, Janssen, & Vaitl, 1986).

Conclusions

The preceding data suggest that physical exhaustion, metabolic challenges, and sexual activity exert, directly or indirectly, a strong influence on brain functions. Here it becomes evident that the subjective experiences may differ considerably according to the deficits or surpluses in energy supply to the brain, provoked by extreme environmental conditions or behavioral practices.

Psychologically Induced ASC

In Eastern cultures, methods for altering consciousness are embedded in religion and the philosophy of human destiny and personal growth, whereas the Western approach mainly focuses on scientific exploration of human consciousness by denuding its alterations of religious context and philosophical interpretation. The induction procedures reviewed in the following paragraphs cover a wide range from practices such as meditation and drumming to experimental stimulation procedures and clinical interventions.

Sensory Deprivation, Homogenization, and Overload

Sensory deprivation. Abolishing or minimizing external sensory input to the human brain affects all levels of human functioning. Suedfeld (1980) has suggested differentiation between sensory deprivation following total sensory loss due to trauma or disease and conditions in which environmental stimulation is not blocked totally but limited in terms of its variability, patterning, meaningfulness, or physical intensity.

Research on restricted environmental stimulation has usually been conducted by exposing subjects to specially designed chambers (Zubek, Hughes, & Shephard, 1971) where visual and auditory stimulation was strongly minimized temporarily. A further method was based on the use of floatation tanks (Lilly, 1977), where visual and auditory restriction is supplemented by a significant reduction of tactile stimulation. In addition to sensory restriction by isolation chambers, floatation-based minimal stimulation further induces the illusion of low gravity and a sensation of true floatation (Suedfeld, 1980).

It has been shown that restricted environmental stimulation significantly affects a number of physiological functions in humans, including reductions of plasma levels of epinephrine, norepinephrine (Hamad, Fine, & Turner, 1996; Lilly, 1956), and stress hormones (Schulz & Kaspar, 1994; Turner & Fine, 1983). Furthermore, restriction of sensory input was shown to be associated with an increase of beta-endorphin levels in the peripheral blood not seen in a relaxation control condition (Turner & Fine, 1983).

Further effects of restricted stimulation have been demonstrated for memory functions, creativity, perception and signal detection, social cognition, and the readiness to change one's attitudes on social phenomena inducing increased motivation to change critical and maladaptive behavior patterns (for a summary, see Atkinson, 1993; Suedfeld, 1980). Autobiographical life episodes were retrieved more intensely and recalled more pleasantly after participation in a restricted stimulation treatment as compared with a normal rest condition (Suedfeld & Eich, 1995). Furthermore, when exposed to a recognition memory test for words and unfamiliar faces (validated on neurological patients with left and right hemispheric lesions, respectively) before and after restricted stimulation, subjects showed better performance following restricted stimulation than following a control condition. Memory performance indicated a significantly greater enhancement of right hemispheric processing after floatation than after the control condition (Raab & Gruzelier, 1994). Additionally, it was shown that subjects recovering from electroconvulsive shock therapy showed less severe memory loss when exposed to restricted stimulation immediately after shock therapy as compared with a condition in which subjects simply returned to their hospital room (Suedfeld, Ramirez, Remick, & Fleming, 1989). Evaluation of the effects of floatation isolation on creativity showed an increase in vigor and a maintenance of curiosity scores (Forgays & Forgays, 1992). Furthermore, tests on creative thinking following a 30-min restricted stimulation period as compared with a control condition revealed that novel ideas generated after restricted stimulation were more creative than those developed in office sessions. Restricted stimulation was associated with trends toward higher levels of vigor and lower levels of tension, anger, depression, fatigue, and confusion (Suedfeld, Metcalfe, & Bluck, 1987).

Sensory hallucinations do not represent a common phenomenon of restricted stimulation. In one study (Schulman, Richlin, & Weinstein, 1967), only 2% of subjects reported percepts of an outside stimulus not being physically present, but 74% of subjects reported on the experience of visual percepts that appeared under some control of the subjects. Earlier studies by Zuckerman and his group (Zuckerman, Persky, & Link, 1969) have shown that in most cases of sensory minimization, hallucinatory percepts are transient and impersonal in quality and mostly nondynamical and nonpsychopathological in nature. They are mostly addressing the visual modality and are composed of simple features, like sudden occurring flashes, colors, or changes of hues (Zuckerman et al., 1969). Hallucinatory percepts occur most frequently during states of medium to high physiological arousal. Some studies have also pointed out that reports on such illusions and hallucinations might more likely be the result of instruction given to subjects prior to the exposure than phenomena occurring spontaneously (Suedfeld, 1980).

Further studies have reported changes of saturation and luminosity of colors (Zubek, 1969), have noted misperception of motion and the shape of objects, or have found evidence for afterimages (Zubek, 1969). Evidence for impairment of depth perception, visual acuity, size constancy, discrimination and contrast of brightness, and kinesthetic acuity (Zubek, 1969) could not be replicated (Suedfeld, 1980).

The same is true for time perception. For example, confinement of subjects for 72 hr did not affect subjects' estimation of time spent in an isolation chamber independently of their behavioral activities. Over- or underestimation of time was associated with periods of higher behavioral activity, whereas during periods of fewer time estimation errors, behavioral activity levels were poorer (Sugimoto, Kida, Teranishi, & Yamamoto, 1968). When groups were examined before and after restricted environmental stimulation with floatation and without floatation, using a tactile object-discrimination task carried out with each hand separately while blindfolded and a recognition memory test for words and unfamiliar faces, the floatation group showed a significantly greater enhancement of right hemispheric processing after floatation than was found when retesting the controls. The direction of the lateral imbalance was similar to hypnosis (Raab & Gruzelier, 1994).

To what extent changes of perception during restricted environmental stimulation relate to different neural activities of the human brain has not been established systematically. Although EEG studies during restricted environmental stimulation have shown changes of alpha-, beta-, and theta-band activities in general (see Suedfeld, 1980; Zubek, 1969), systematic studies on brain electric concomitants of visual, auditory, and other sensory changes, illusions, and hallucinations are widely lacking. ASC have been seen only in subjects who have had a number of prior experiences with such phenomena due to prior exposure to meditation or consumption of psychedelic drugs or who were instructed that such phenomena might arise while they were exposed to restricted stimulation environments (Zubek, 1969). Whether ASC are a common consequence of sensory deprivation has not been settled by systematic empirical research.

Sensory homogenization ("ganzfeld"). *Ganzfeld* is a technical term for an unstructured, perfectly homogeneous perceptual, usually visual field (Avant, 1965; Wertheimer, 1923/1938). A longer exposure (from minutes to a few tens of minutes) to visual ganzfeld (a homogeneous red light field) and auditory ganzfeld (monotone noise, e.g., "white" or "pink" noise) may induce an ASC characterized by episodes of imagery ranging from simple sensory impressions to hallucinatory, dreamlike experiences. As for subjective experience, visual imagery is most frequently reported; less frequently reported are percepts involving other sensory modalities. Procedurally, ganzfeld is closely related to sensory deprivation, but the physical level of sensory stimulation is kept at medium to high levels. Subjectively, ganzfeld imagery is similar to hypnagogic imagery (see *Hypnagogic States*). It was hypothesized that ganzfeld induces a kind of experimental hypnagogic state (Braud, Wood, & Braud, 1975; Schacter, 1976), that is, a decrease of vigilance (see *States of Drowsiness*). Little is to be said about behavioral correlates: Because of environmental restrictions, subjects in ganzfeld can show little overt behavior, except verbal responses. Subjects' verbal expression is often less organized than in waking-state reports (see, e.g., Honorton et al., 1990). This may be due partly to the unusual, dreamlike nature of ganzfeld experience and not necessarily to impairment of cognitive functions. It was assumed (Honorton & Harper, 1974; Parker, 1975) that ganzfeld induces a state favorable to "extrasensory perception," which would then constitute a special class of ASC correlates; however, experimental findings are still controversial (Bem & Honorton, 1994; Wiseman & Milton, 1999). Time awareness is little affected by ganzfeld; verbal estimates of elapsed time intervals (5–15 min) showed a tendency to underestimate comparable with the waking state (Wackermann et al., 2001).

A large study comparing physiological correlates of ganzfeld, sleep onset, and relaxed waking state showed EEG spectra in ganzfeld to be more similar to wakefulness than to the sleep onset state, with slightly accelerated alpha activity; there were no EEG markers indicating decreased vigilance (Wackermann et al., 2000, 2002). Thus, the hypothesis of a hypnagogic basis to ganzfeld imagery has not been supported. In a follow-up study, EEG correlates of vivid imagery were studied with selected "high responders" to ganzfeld. Intraindividual comparisons against no-imagery EEG revealed mostly triphasic courses, consisting of (a) an initial alpha increase, (b) a burst of accelerated alpha-2 activity (10–12 Hz), and (c) a deceleration and reduction of alpha rhythm and an undulating increase of beta-2 (18–21 Hz) and beta-3 (21–30 Hz) power, indicating a transition from relaxation to outward directed and fluctuating attention and finally preparation for the mentation report (Wackermann, Pütz, & Braeunig, 2002).

Sensory overload. There is a long tradition of attempting to induce ASC by sensory overload. However, models of sensory overload are rare. Vollenweider and Geyer (2001) proposed a cortico–striato–thalamo–cortical loop model of psychosensory processing. It was suggested that a deficient thalamic filter, which had been conceptualized in animal models by using the prepulse inhibition paradigm, enables sensory overload of the cortex. Progress in knowledge about the relationship between sensory overload and brain function and accordingly on consciousness-related functions is mainly based on clinical research, in areas including schizophrenia, intensive care unit syndrome, autism, and use of hallucinogens.

In schizophrenia (see *Psychotic Disorders*), the subject's ability to inhibit irrelevant stimuli from the environment is impaired. This deficit is hypothesized to cause sensory overload in schizophrenic patients and successively lead to disorganization and thought disorders (Ludwig, 1972; Ludwig & Stark, 1973). A cluster of psychiatric symptoms that are unique to the intensive care unit environment have been suggested to be caused, among other reasons, by sensory overload or monotony (Glide, 1994; Steinhart, 1978; Vasquez & Chitwood, 1975). The effects of sleep deprivation on physiological and immune system functions have been discussed as one starting condition for sensory overload in the intensive care unit (Halm & Alpen, 1993; Schwab, 1994). McGuire, Basten, Ryan, and Gallagher (2000) have suggested that intensive care unit psychoses are delirium states that are exclusively caused by organic stressors. It has been speculated that autism is partly a consequence of sensory overload caused by a reduced ability for sensory filtering in the framework of an unidentified neurological disorder (Bristol-Power & Spinella, 1999).

One of the rare studies with healthy subjects (Brauchli, Michel, & Zeier, 1995) found both effects on subjective ratings and increased autonomic arousal during conditions of massive sensory stimulation but failed to reveal effects on electrophysiological brain activity. Obviously, a particular vulnerability of brain function is necessary for sensory stimulation to become an overstimulation.

Rhythm-Induced Trance (Drumming and Dancing)

Drumming and dancing have been practiced since ancient times to induce altered states and are still common today. They may result in trancelike states characterized by a “narrowing of awareness of immediate surroundings, or unusually narrow and selective focusing on environmental stimuli” and by “stereotyped behaviors or movements that are experienced as being beyond one’s control” (American Psychiatric Association, 1994, p. 729). In the case of drumming and dancing, the rhythmic body movements become synchronized with the beat and finally seem to happen automatically, without effort or voluntary control. Self-reflective thinking ceases when the subject becomes increasingly absorbed in the action. In addition, alterations also include a distortion of the time sense, unusual bodily sensations (e.g., feeling light, warm, energized), vivid imagery, and strong positive emotions (e.g., joy, happiness, ecstasy) in conjunction with the impression of becoming one with the rhythm.

In contrast to the ubiquity of the phenomena, modern science has scarcely investigated the psychobiological foundations of these human activities. Neher (1961, 1962) was the first to study the effects of monotonous drumming on the EEG. He found that drum beats (3–8 Hz) can induce EEG waves of the same frequency (“auditory driving”), and he speculated that this phenomenon may be responsible for the facilitation of trance states. Later on, the role of physiological stimulation was questioned by Rouget (1980), who emphasized the impact of the social setting. This issue was further explored by Maxfield (1990), who studied the effects of different beat rhythms on the EEG and subjective experiences. She found more theta EEG activity while the subjects were listening to rhythmic monotonous and patterned drum beats than when they heard unstructured beat sequences. The alterations in consciousness included changes in time sense and body image, enhanced imagery, and other experiences resembling descriptions of a shaman’s journey. In a study by Maurer, Kumar, Woodside, and Pekala (1997), relaxation and similar shamanic-type experiences (e.g., dissociation from the body, tunnel experiences) were evoked by monotonous drumming, especially in medium and highly hypnotizable subjects.

Besides rhythmical auditory stimulation, the social setting, and personality traits (e.g., absorption), a fourth factor—namely, the rhythmic body movements during drumming and dancing—may play an important role for trance induction. Rhythmic body movements are accompanied by recurrent shifts in body fluids, especially in the blood. In addition, respiration tends to synchronize with movements and induces the heart rate oscillations known as respiratory sinus arrhythmia. In this way, rhythmic movements may result in a respiratory–cardiovascular synchronization with increased blood pressure oscillations that stimulate the carotid baroreceptors. The effects of baroreceptor stimulation are not confined to a slowing of the heart rate; they also reduce cortical arousal and excitability (Rau, Pauli, Brody, Elbert, & Birbaumer, 1993; Vaitl & Gruppe, 1995). Many effects of barostimulation—like augmented pain thresholds, increased theta activity, and reduced muscular reflexes—resemble typical features of trance states. To investigate whether cardiovascular oscillations induced by body movements contribute to trance induction, a series of experiments was conducted using a tilt table. The subjects were rhythmically tilted between −6° head-down and 12° head-up. The tilting movements were triggered by respiration that was paced at 0.125 Hz. In one condition, the respiratory oscillations of the heart rate were amplified; in the other condition they were dampened (Vaitl, Sammer, & Ott, 2000). During the condition with increased heart rate variability, the power in the EEG theta band was increased and the cross-spectral power between pupil oscillations and respiration was reduced, indicating cortical inhibition. The subjects reported drowsiness, disorientation, and even hallucinations. They reached moderate hypnoidal scores on the Phenomenology of Consciousness Inventory (Pekala, 1991). Furthermore, it was found that those subjects responding differently to the two tilting conditions had significantly higher scores on Tellegen’s Absorption Scale (Tellegen & Atkinson, 1974; German version by Ritz & Dahme, 1995) compared with the nonresponders. This finding was replicated in a second study with continuous blood pressure measurement. Again, baroreflex sensitivity correlated significantly with the absorption score (Ott, Sammer, & Vaitl, 2002) pointing to a connection between the cardiovascular responsiveness and the personality trait of absorption, which is positively correlated with hypnotic susceptibility (Kumar & Pekala, 1988).

In summary, the synchronization of the cardiovascular system and the augmented stimulation of the baroreflex by increased blood pressure oscillations may contribute to the efficacy of rhythmic trance-induction procedures, and this should be taken into account in addition to sensory stimulation, personality characteristics, and situational variables.

Relaxation

There is a wide range of techniques by which relaxation and ASC can be induced. The commonly applied and clinically established methods for body relaxation are progressive muscle relaxation, autogenic training, biofeedback, and meditative practices. The cognitive–behavioral model of relaxation (Smith, Amutio, Anderson, & Aria, 1996) suggests that three elements are basic to all forms of relaxation: (a) focusing, the ability to maintain concentration on and return attention to simple stimuli (acoustic or visual) for an extended period of time; (b) passivity, the ability to refrain from goal-directed and analytic thoughts; and (c) receptivity, the ability to tolerate and accept unusual or paradoxical experiences. Benson (Benson, 1975; Greenwood & Benson, 1977) proposed that almost all relaxation techniques elicit a general "relaxation response" consisting of physiological changes that are mainly evoked by decreased autonomic nervous system activity, such as slowing of heart rate, slow and shallow breathing, peripheral vasodilation, reduced oxygen consumption, and decrease in spontaneous skin conductance responses (cf. Lichstein, 1988; Shapiro & Lehrer, 1980). Specifically, these effects are mainly brought about by a reduced sympathoadrenergic reactivity, but not, as often erroneously believed, by increased parasympathetic activity.

Neurophysiologically, the relaxation response is most frequently accompanied by changes in EEG indicating reduced cortical arousal. Insofar as relaxation techniques are focused on reduced oculomotor activity or refrain from vivid imagery of overt movements, increases in EEG alpha frequency may be expected to occur (Peper, 1971). G. D. Jacobs and his coworkers (1996) found in novices undergoing the progressive muscle relaxation technique while listening to taped relaxation instructions a significant reduction in the EEG beta frequency band, exclusively in the frontal lobe sites. In none of the other 13 electrode sites could EEG differences be observed between the relaxation and the control group. The peripheral physiological effects are most likely to follow the reduced cortical arousal measured by EEG (Narita, Morozumi, & Yagi, 1987). Beyond these general changes in electrocortical activity during relaxation, more specific alterations are likely to occur. For instance, Isotani, Tanaka, and collaborators (2001) investigated the specific engagement of different brain regions during hypnosis-based suggestion of relaxation compared with suggestion of negative emotion, such as anxiety. Relaxation showed maximally stronger activity compared with anxiety in the left superior temporal gyrus (Brodman Area 22). During the two induced emotional states, brain activity shifted to the right hemisphere in the frontotemporal regions during negative compared with positive emotions (relaxation). The excitatory frequency EEG band of beta-2 (18.5–21.0 Hz) showed the strongest relaxation-related effect on location, with the source gravity center located less right sided during relaxation than during anxiety. The lateralized differences of brain activity during the two conditions were clearly not mirror symmetric in the two hemispheres. Relaxation showed strongest activity differences in left temporal areas, and negative emotion in right frontal areas.

In addition, neuroimaging studies have suggested that various brain regions and systems are involved when subjects intentionally try eliciting decreases in sympathoadrenergic tone. Critchley, Melmed, Featherstone, Mathias, and Dolan (2001) used PET to investigate cerebral activity relating to biofeedback-assisted relaxation and modulation of sympathetic activity. The voluntary control of bodily arousal was closely related to enhanced activity of the anterior cingulate cortex, which is thought to be engaged in the integration of cognitive control strategies and bodily responses. As Critchley, Corfield, Chandler, Mathias, and Dolan (2000) demonstrated, these relations were lateralized. The observed predominantly left cingulate activity was associated with the intention to relax, which contrasted with right cingulate activity observed during task-related states of sympathetic arousal.

Almost all relaxation techniques apply various interventions to prevent subjects from falling asleep after they have left the state of full alertness and approach the critical threshold of sleep onset (showing significant EEG signs, such as K-complex and sleep spindles). Therefore, trainees gradually learn to circumvent all usual sleep-promoting activities and imageries as soon as they have left the stage of full alertness by initiating the relaxation response. The better they are trained, the longer they can stay within this particular intermediate stage between decreased arousal and falling asleep. This provides the opportunity for making new experiences similar to those described for hypnagogic states. These novel experiences may be subjectively considered as ASC.

In summary, the various techniques applied to induce a relaxation response are viable tools to reduce autonomic and central arousal, which may, in turn, predispose the body and the mind for accepting unusual or paradoxical experiences occurring during ASC. Basically, they are not directly aiming at ASC, but whenever they occur, they are treated as tolerable side effects. In this sense, relaxation techniques are helpful and indispensable adjuncts in the realm of ASC.

Meditation

A great variety of meditation techniques exist that can be divided into those involving movements, like walking, dancing, and singing, and the "silent" meditation methods, which are usually practiced in a characteristic sitting position. Instructions on how to meditate are manifold, ranging from more receptive "wide focus" techniques to those requiring intensive concentration on external objects, imaginings, or parts of the body. The transcendental meditation technique, introduced to the West by Maharishi Mahesh Yogi (1966), is a yogic "mantra" meditation: A syllable is silently repeated in a passive, effortless manner. The procedure is quite standardized, and it has been investigated more frequently than other methods (Murphy & Donovan, 1997).

The subjective experience during transcendental meditation has been described as a state of blissful mental quiescence where thoughts are absent but consciousness remains—referred to as a state of "transcendental consciousness" (Travis, 1993). The occurrence of transcendental consciousness has been frequently associated with short periods of breath suspension, while breath period, magnitude of heart rate deceleration, and skin conductance level have been found to be greater during periods of transcendental consciousness (Travis & Wallace, 1997). Results such as these led to the suggestion that such autonomic activity reflected the transition of awareness from active thinking processes to the silent yet alert state of transcendental consciousness (Travis, 1993).

Changes in the EEG during meditation, such as an increase in alpha activity, are nonspecific and do not support the notion of a unique state of consciousness. This holds true also for increased EEG coherence found during transcendental meditation, which has been interpreted as reflecting an "ordering of the mind" (see Fenwick, 1987, for a critical discussion). Recent research comparing subjects who have undertaken meditation for periods longer than 3 years with those practicing for less than 6 months has shown a difference in slow wave theta activity (Aftanas & Golocheikine, 2001) similar to earlier findings (Hebert & Lehmann, 1977). Long-term meditation was characterized by increased theta EEG activity over the frontal region. The intensity of the blissful experience correlated with increases in theta power in anterior–frontal and frontal–midline regions. Moreover, long-term meditation was associated with increased theta synchronization between the prefrontal and the posterior association cortex, peaking in the left prefrontal region. This is compatible with investigations into EEG coherence during the experience of positive and negative emotions, which suggest that theta activity, peaking in the left prefrontal region, is indicative of emotionally positive experiences (Aftanas, Varlamov, Pavlov, Makhnev, & Reva, 2001), and with reported emotional differences between short- and long-term meditators (Easterlin & Cardeña, 1998).

Recently, several theory-based studies have been carried out that link specific meditation techniques and experiential characteristics to certain changes in brain function. Lehmann, Faber, Achermann, et al. (2001) investigated an advanced subject who was able to enter voluntarily distinct meditative states by applying different meditation techniques. They found different centers of gravity of gamma EEG activity related to the nature of the respective meditation technique (visualization: right posterior; verbalization: left central; “dissolution of the self”: right anterior) using a repeated measurements design. Lazar et al. (2000) conceptualized meditation as voluntary regulation of attention. Their subjects, who had practiced a breathing meditation for many years, were trained to meditate during fMRI. They found an activation of neural structures involved in attention and in the control of the autonomic nervous system and a signal decrease apparently related to the slower breathing during the meditation phases. In a similar way, certain experiential features of meditative states, like the sense of becoming one with the object of meditation, have been linked to the blocking of a parietal cortical area during meditation (revealed by single positron emission computed tomography) that represents the position of the body in three-dimensional space (Newberg & d’Aquili, 2000).

In summary, it seems promising that the traditional meditation methods are becoming more and more examined scientifically. A cognitive analysis of the meditation methods and the study of trained subjects within established and newly devised experimental paradigms will help to elucidate the psychophysiological bases of the human capability to enter into different ASC through the intentional self-regulation of attention.

Hypnosis

After 200 years of inquiry, there is still great controversy over how hypnosis should be defined. Throughout its history, the field has been divided between those who evoke distinctive psychological processes and those who appeal to the ordinary processes that underlie everyday behavior. The altered state view we take in this article attempts to develop the former approach within a contemporary neurophysiological framework. Hypnosis is a procedure that may or may not involve an ASC, and the latter is not necessary for most hypnotic phenomena (Cardeña, Lynn, & Krippner, 2000).

Traditionally, hypnosis is induced by a ritual, administered by the hypnotist and believed in by the subject. Induction rituals may vary greatly in content. For example, progressive relaxation instructions, riding an exercise bike, and sounding a gong have all been reported as successful induction rituals. The induction ritual is followed by a series of verbal suggestions for seemingly unusual changes in experience, behavior, and cognitive control. Suggestions may be given to behave in ways that are experienced as involuntary, to be unable to behave in ways that are normally voluntary, or to experience changes in belief, perception, or memory that are at odds with the actual state of affairs. Hypnosis may be self-induced or other-induced. However, the relationship between autohypnosis and heterohypnosis is poorly understood. Traditional hypnotic phenomena have also been shown to be able to be produced by suggestion alone without the administration of a formal induction procedure, although the interpretation of these findings is controversial. Today hypnosis has many clinical applications, including relief of pain, as an adjunct to facilitate the effectiveness of specific psychotherapeutic interventions, and is under investigation as a modulator of immune system functioning.

The effectiveness of hypnotic suggestion in producing corresponding changes in experience (i.e., hypnotic susceptibility) varies greatly from individual to individual and is a highly stable attribute of the person. Current theories of hypnosis emphasize the enactment of self-directed cognitive strategies (Spanos, 1986), response expectancies (Kirsch, 2000), or alterations in central executive control (Bowers, 1992; Farvolden & Woody, 2004) as processes mediating response to hypnotic suggestion. Assessment of susceptibility and psychological research have focused on behavioral responses during hypnosis, but the core phenomena lie at the level of experience (Sheehan, 1992). Identical behavioral responses often mask widely divergent phenomenology and cognitive strategies evoked in different individuals by the same hypnotic suggestion (Sheehan & McConkey, 1982), and it is essential that adequate studies of hypnotic phenomena ensure they are comparing subjects with similar phenomenological as well as behavioral responses (Woody & McConkey, 2003).

The neurophysiology of hypnosis has been the subject of numerous studies over the past 40 years, reporting on multiple changes in many different physiological parameters (for reviews, see, e.g., Crawford, 1994; Crawford & Gruzelier, 1992; Gruzelier, 1998, 2000). The bulk of this research has used conventional evoked potential or frequency analysis of EEG data (De Pascalis, 1999; Ray, 1997; Williams & Gruzelier, 2001). For example, a number of studies investigated electrophysiological characteristics of hypnotic susceptibility. These studies reported various differences between high- and low-hypnotically susceptible subjects in different EEG bands. For example, higher power in the theta frequency band in some studies, higher gamma power over the right hemisphere, and higher global dimensional complexity all were reported for high-susceptible subjects (for an overview and recent results, see Isotani, Lehmann, et al., 2001). However, until now no neurophysiological measure or set of measures has been able to reliably categorize data as obtained from hypnotized or nonhypnotized individuals (Wagstaff, 1998). Positive findings are rarely replicated. Besides the large amount of available data, the methodological heterogeneity and complexity of reported findings make clear comparisons very difficult. One reason for this diversity may be that differences in specific suggestions between studies induce corresponding variability in observed behaviors, for example, emotions, postures, relaxation, and so forth (e.g., Isotani, Tanaka, et al., 2001).

Gruzelier (2000), for the past decade, has consistently advocated the view of hypnosis as a form of frontal inhibition. Replicated neuropsychological findings (Gruzelier & Warren, 1993; Kallio, Revonsuo, Hamalainen, & Gruzelier, 2001) show impaired letter fluency (left frontal) but not category fluency (left temporal) performance during hypnosis for subjects high but not low in hypnotic susceptibility. This suggests that for hypnotizable subjects, hypnosis is associated with inhibition of the left dorsolateral prefrontal cortex (Gruzelier, 1998). Selective influences within the cingulate have also been inferred from evidence of the maintenance of the error-related negativity wave in concert with an abolition of the ensuing positivity wave in highly hypnotizable subjects during hypnosis (Kaiser, Barker, Haenschel, Baldeweg, & Gruzelier, 1997). Some recent studies investigated hypnotic analgesia to test the hypothesis that at least part of the phenomena occurring under hypnosis might also be explained by a dissociation between functional subunits organizing conscious behavior. Thus, Croft, Williams, Haenschel, and Gruzelier (2002) analyzed EEG component frequencies in the period following painful electrical stimulation of the right hand in a control condition, during hypnosis, and after hypnotic analgesia suggestion. Prefrontal gamma EEG activity localized in the anterior cingulate cortex predicted the intensity of subjects' pain ratings in the control condition. This relationship remained unchanged by hypnosis for the subjects with low susceptibility but was abolished in highly hypnotizable subjects following instructions of hypnosis.

Lehmann, Faber, Isotani, and Wohlgemuth (2001) investigated intracerebral source locations during hypnotically suggested arm levitation versus willful initiation of arm raising in highly hypnotizable subjects. They found sources for delta and theta EEG activity more posteriorly and for alpha and beta-1 activity more anteriorly in the hypnotic arm levitation condition, suggesting the co-occurrence of electrophysiological characteristics of lowered vigilance and increased attention.

Friederich et al. (2001) compared the effects of hypnotic analgesia and distraction on processing of noxious laser heat stimuli in highly susceptible subjects. They examined whether hypnotic analgesia and distraction share similar cortical mechanisms (Crawford, Knebel, & Vendemia, 1998). Friederich et al. (2001) found significantly reduced pain reports during both hypnotic analgesia and distraction compared with the control condition but significantly smaller amplitudes of the late laser-evoked brain potential components during distraction as compared with hypnotic analgesia. Furthermore, coherence analysis of neural oscillations between different areas of the brain indicated a significant decrease of coherence within the gamma band between somatosensory and frontal sites of the brain while subjects were hypnotized as compared with the control condition. This loss of coherence between somatosensory and frontal brain areas during hypnotic analgesia was hypothesized to reflect a breakdown of functional connectivity between the brain areas involved in the analysis of the somatosensory aspects of the noxious input and areas organizing the emotional and behavioral responses to pain. Thus, hypnotic analgesia and distraction appear to involve different brain mechanisms, probably an early attentional filter for distraction but a dissociation between early sensory and later higher order processing of noxious input for hypnotic analgesia. These results are consistent with neodissociation theories of hypnosis and hypnotic pain control (Hilgard & Hilgard, 1983; Miller & Bowers, 1993) and recent studies demonstrating a dissociation between processing of somatosensory and affective information during hypnotic analgesia by both behavioral and regional cerebral blood flow data (Rainville, Carrier, Hofbauer, Bushnell, & Duncan, 1999).

These studies suggest that hypnosis affects integrative functions of the brain and induces an alteration or even a breakdown of communication between subunits within the brain responsible for the formation of conscious experience (see *Functional Integration and Breakdown of Connectivity*).

Biofeedback

Contemporary research supports the view that biofeedback and instrumental learning of neuronal activity is a promising noninvasive methodology to manipulate brain activity as an independent variable and observe ASC as the dependent variable (see Birbaumer & Kimmel, 1979). The objective of biofeedback is a greater awareness and voluntary control over physiological processes. Various methods have proven to be effective in supporting people's efforts to exert control over physiological processes, such as heart rate, blood pressure, vasomotor responses and temperature, respiratory activity, gastrointestinal reactions, and levels of muscular tension (for a review, see Schwartz, 1995). In the late 1960s and the early 1970s, biofeedback of EEG alpha rhythm was believed to alter states of consciousness (Kamiya, 1969). It had been shown that subjects could learn to discriminate whether they were in an alpha or in a beta state, and by means of the brain wave biofeedback, they could produce alpha brain waves at will. At a certain level of alpha wave production, the verbal reports of these subjects suggested a state of serenity, meditative mood, and happiness. This led some researchers to hypothesize that states of consciousness can also be modified by brain wave feedback, as with meditation and hypnosis.

Recently, neurofeedback has been developed as a form of biofeedback linked to aspects of the electric activity of the brain such as frequency, location, or amplitude of specific EEG activity. It therefore aims directly at altering electrocortical processes associated with cortical excitability, arousal, and central control of motor performance. For this purpose, EEG components are extracted online and fed back to subjects by various devices producing acoustic and visual signals that can be shaped with operant conditioning strategies or cognitive manipulations. The modulation of cortical activity is usually achieved through a training process involving real-time representation of EEG parameters paired with positive reinforcement to facilitate successful operant learning of the desired response (Egner & Gruzelier, 2001). Many authors have demonstrated operant conditioning and self-regulation of various EEG parameters in animals and humans in experimental and clinical settings (Birbaumer, 1977, 1984; Birbaumer, Elbert, Rockstroh, & Lutzenberger, 1981; Kamiya, 1969; Kuhlman, 1978; Plotkin, 1976; Sterman, 1977). Sterman and Shouse (1980) demonstrated that epileptic seizure incidents can be reduced by the conditioned enhancement of a low beta-band 12–15 Hz EEG rhythm, *sensorimotor rhythm* (SMR or μ-rhythm), over sensorimotor cortex. These findings are interpreted as improved response inhibition by SMR feedback training. Sterman (1996) supposed that the SMR training may lead to increased inhibitory activity of thalamic nuclei interacting with somatosensory and sensorimotor cortex. In the same vein, Egner and Gruzelier (2001, 2004) postulated that similar inhibitory activity may account for alleviation of performance errors in student volunteers during sustained attention tasks deficit, as in subjects with attention-deficit/hyperactivity disorder. Learning the ability to increase relative and absolute SMR (12–15 Hz) amplitude correlated positively with improvement of attentional performances and reduction of impulsiveness, whereas the opposite was true for the enhancement of beta-1 (15–18 Hz). The relationship between learning to enhance SMR over sensorimotor cortex and reduced impulsiveness again supports the notion that inhibitory processes are mediating behavioral and cognitive improvements. Furthermore, the combination of SMR and beta-1 EEG training has provided evidence, with both behavioral and event-related brain potentials (ERP), of being effective in integrating sensory input and counteracting fast motor response tendencies and error-prone behavior. Similar frequency-specific effects of neurofeedback were found for cognitive processes, such as working memory (Vernon et al., 2003) and attention (Egner & Gruzelier, 2004).

Another EEG parameter is the *slow cortical potentials* (SCP). Negative shifts of slow EEG changes reflect widespread depolarization of apical dendrites of pyramidal neurons (Birbaumer, Elbert, Canavan, & Rockstroh, 1990) and decrease of thresholds for paroxysmal activity. In healthy subjects, it has extensively been confirmed that SCP can be brought under voluntary control (Birbaumer et al., 1991). Thus, it was obvious to use the SCP feedback as an adjunctive treatment for drug-refractory epilepsy. Several studies have shown that epilepsy patients are able to acquire self-control skills after an extensive training of SCP self-regulation, resulting in a significant decrease of seizure rate (Kotchoubey et al., 1996, 1999; Kotchoubey, Strehl, et al., 2001; Rockstroh et al., 1993).

Moreover, the self-regulation of SCP can be used for brain–computer communication. It may be needed for patients suffering from neurological diseases leading to total motor paralysis caused by amyotrophic lateral sclerosis (ALS) or brain stem infarct ("locked-in" patients). Brain–computer interfaces provide them with a system for communication, where a cursor on a screen is moved (vertically or horizontally) by changes in self-regulated SCP in both directions, that is, by shifts in SCP negativity. Birbaumer and his group have developed a thought translation device and a training procedure that enables patients with ALS, after extensive training, to verbally communicate with other people without any voluntary muscle control (Kübler, Kotchoubey, Kaiser, Wolpaw, & Birbaumer, 2001).

Currently there are growing applications of neurofeedback that show that patients have benefited by learned self-control of EEG parameters as EEG mechanisms underlying psychopathological and neurological disorders are better understood. This was underpinned by Gruzelier, Hardman, Wild, and Zaman (1999), who trained schizophrenic patients by SCP feedback to reduce their interhemispheric imbalance, which as been shown to be syndrome related (for a review, see Gruzelier, 1999a).

Despite the fact that neurofeedback is a powerful tool for gaining self-control over brain electric activity, the lack of biofeedback-induced ASC may indicate that biofeedback of brain responses of one or a few electrodes (i.e., brain areas) is not an induction method powerful enough to induce such alterations. This conclusion, however, may be premature before serious attempts to produce ASC appear in the scientific literature, and recently, replicable efficacy of training to elevate theta over alpha activity for enhancing music performance (including ratings of interpretative imagination) in conservatoire students has been reported (Egner & Gruzelier, 2003). Improvements in attention and semantic working memory in medical students support this view (Egner & Gruzelier, 2001, 2004; Vernon et al., 2003). If EEG/MEG reflects ASC, as discussed in this article, learning to induce those EEG/MEG patterns underlying ASC should lead to those states.

Conclusions

There is a huge body of literature linking ASC induced by psychological induction procedures to changes in brain activity. Although early studies were in most cases limited to the mere description of correlations, the emerging new approaches try to develop functional models that explain how distinct changes in cognition and consciousness are produced and devise specific experimental paradigms to test these models.

Disease-Induced ASC

There are numerous pathological processes that can result in various degrees of ASC. Most of these disorders affect, directly (within the brain) or indirectly (in the periphery), structures that are responsible for dramatic shifts on the wakefulness–coma axis toward clouding of consciousness, obnubilation, somnolence, sopor, and coma. Regional brain lesions as well as high-level deefferentation and deafferentation (e.g., through a spinal cord injury or ALS) are not reviewed here, because they typically result in a loss of circumscribed functions without disturbing consciousness in general. Nevertheless, interest in the psychological concomitants—for example, of the so-called locked-in syndrome—has increased in the past few years, and new devices have been developed that enable communication with these patients (Birbaumer et al., 1999). There exist many other degenerative, developmental, and organic brain diseases that are accompanied by alterations of consciousness (e.g., Alzheimer's disease, Morbus Parkinson, dementia with Lewy bodies, frontotemporal dementia). Although these phenomenological changes have been reported frequently, they have rarely been investigated systematically with respect to the interaction between subjective experiences and specific brain malfunctions. Owing to this scarcity of empirical evidence, these brain diseases are not reviewed here.

Psychotic Disorders

Alterations of conscious experience in psychosis are coming under the scrutiny of cognitive neuroscience, exemplified most keenly by hallucinations and delusions as well as the cognitive disintegration and splitting of psychic functions that defines schizophrenia. An overriding concept is that alterations of consciousness arise from defective connectivity or from defective interactions between distributed brain regions (Fletcher, 1998; Lawrie et al., 2002). Germane to this approach is the evidence that patients with metachromatic leukodystrophy, in whom there is a disorder of frontal white matter, present cognitive symptoms that include thought disorder, hallucinations, and delusions (Hyde, Ziegler, & Weinberger, 1992). In addition, phencyclidine, which inhibits *N*-methyl-D-aspartate glutamatergic transmission, produces positive psychotic symptoms (Thornberg & Saklad, 1996). Historically, the disconnection concept guided research into the nature of interhemispheric connection in schizophrenia on the basis of the split-brain model, giving way to disordered functional interhemispheric connectivity in the absence of evidence of structural disconnection (Gruzelier, 1979; Nasrallah, 1985).

A leading hypothesis is that it is temporally disconnected and abnormal patterns of oscillatory activity that contribute to abnormal mental events and whose underpinning involves integrative thalamocortical circuits. Considering first electrophysiological evidence, gamma oscillations, circa 40 Hz, have been implicated in the "binding" together of regions subserving conscious perception (Llinas & Pare, 1991). Llinas, Ribary, Joliot, and Wang (1994) have proposed that activity of the specific and nonspecific thalamocortical systems underpins conscious experience, conceptualizing the specific nuclei as providing the content of experience and the ascending nonspecific thalamic system as providing level of alertness and context. Accordingly, hallucinations can be regarded as a state of hyperattentiveness to intrinsic self-generated activity in the absence of appropriate sensory input. In support of this proposition, a coincidence between hallucinations and gamma activity has been demonstrated in a patient with pseudosomatic hallucinations, later diagnosed as schizophrenic (Baldeweg, Spence, Hirsch, & Gruzelier, 1998). Neuromagnetic recording has also lent substance to theory. Tononi and Edelman (2000) have demonstrated that conscious experience is underpinned by numerous neuronal groups, representing differentiated states distributed in the thalamocortical system. Through corticothalamic and cortico-cortico reentrant interactions, these rapidly bind together into an integrated neural process or functional cluster. Furthermore, with conscious experience the neuromagnetic response becomes stronger and the cluster more widespread to include frontal, parietal, temporal, and occipital cortices. This in turn is accompanied by increased coherence between distant brain regions, is characterized by strong and rapid interactions between groups of neurons, and is subject to wide individual differences. Tononi and Edelman (2000) examined the PET results of medicated schizophrenic patients during simple cognitive tasks. They found that despite similarities in the topography of cluster boundaries, functional interactions within clusters differentiated patients from controls while levels of activity and functional specialization within the cortex were spared. They noted that a coherent network may be disrupted by multiple pathophysiological mechanisms, many of which have been implicated in schizophrenia at one time or another.

Integrative circuits of the basal ganglia, thalamus, and frontal cortex have also been invoked in modeling schizophrenia as a disorder of integration between the sensory systems of consciousness and the motor systems of thought. Feinberg and Guazzelli (1999) adopted Graybiel's (1997) speculation that innate cognitive pattern generators exist in the motor systems of thought, akin to innate motor pattern generators, proposing that the basal ganglia along with the frontal cortex are involved in the planning of motor acts and are central to the planning and sequencing of cognitive processes. As with the theory of Llinas and colleagues (1994), above, hallucinations, delusions, and disorganized thought were hypothesized to arise through derangement of the ability to distinguish exogenous from endogenous activity, but here the emphasis is on the failure to distinguish self from other (see also Feinberg, 1978). This leads to fragmentation of the senses of self and will, resulting in a subsequent distortion of the boundaries of self.

The diffuse ascending thalamic systems have also been implicated in the hemispheric activational imbalances found in both schizophrenia and schizotypy. These disorders have been associated with an activated syndrome, underpinned by a left hemispheric activational preference, and a withdrawn syndrome having the opposite lateralized imbalance (Gruzelier, 1999a, 2002). Neuroleptic drugs can modify and reverse cognitive and electrophysiological lateral asymmetries. Developmental origins for dispositional imbalances have been posited, in keeping with their manifestation in schizotypy. In animals, behavioral asymmetries occur through the influence of genes, hormones, and early experiences, and in human infants there are spontaneous asymmetries in gesture and emotion soon after birth that influence the approach–withdrawal balance in social encounters (see Gruzelier, 1999a). In schizotypy, factors in the second decade of life may also produce atypical connectivity. Both early and late pubertal timing have been associated with a propensity for unreality experiences (Kaiser & Gruzelier, 1999), thought to reflect individual differences in regressive events such as synaptic pruning halted by the onset of puberty (Feinberg, 1982; Saugstad, 1994).

In sum, interruptions ranging from minor asynchrony to complete uncoupling between the conjunction of specific and nonspecific thalamic systems, and in turn between the content and context of consciousness, could give rise to many aspects of anomalous processing in schizophrenia and schizotypy (Gruzelier, 1999a, 1999b; Oke & Adams, 1987). Such anomalies include disturbances of sensory processing, sensory gating, and magnocellular functions; of perceptual aberrations, of hallucinations, and with attributions of schizophrenia to a waking dream; of dysregulation of orienting, arousal, alertness, and attention; of mismatches between ongoing and past experiences that may lead to erroneous and delusional thinking (for a review, see Behrendt & Young, in press; Gruzelier, 1999b); and to truncated microstates (see *Fine Structure of Brain Functional States and States of Consciousness*).

Coma and Vegetative State

Coma and vegetative state are typically regarded as a decrease or even a complete loss of consciousness. However, in light of modern data obtained with PET and ERP, these conditions can alternatively be conceived of as involving far-going fragmentation of the field of awareness, whose single modules may continue to work independently of other modules, probably switched off. Very simple stimuli may not be the best means to probe the function of these disintegrated modules; rather, the optimal level of task complexity is required.

Coma is defined as a complete or nearly complete loss of all basic functions of consciousness: vigilance, mental contents or experience, and selective attention (Niedermeyer, 1999). The basis of this condition is a deep dysfunction of brain stem structures regulating sleep and wakefulness. A primary cortical damage is not necessary for coma. The main behavioral sign of coma is a profound suppression of all responses, which ranges from weak responses to intensive stimuli to complete nonresponsiveness. Several scales have been developed to measure these differences in degree denoted as the "depth" of coma (e.g., Gentleman, 1999).

Patients surviving coma often pass to another condition called *vegetative state* (Wade & Johnston, 1999). In contrast to coma, most brain stem functions are preserved in this condition, but all cortical functions are assumed to be lost. Thus, vigilance is preserved, and patients have close to normal sleep–wakefulness cycles. However, mental contents and selective attention are believed to be lost. Subcortical responses are usually preserved and often even enhanced, but responses mediated by the cortex are lacking. In many patients, however, very weak and inconsistent "cognitive" responses are observed by doctors and the personnel. This borderline condition is referred to as *minimal consciousness state* (American Congress of Rehabilitation Medicine, 1995; Whyte, DiPasquale, & Vaccaro, 1999). Clinical differentiation between vegetative state and minimal consciousness state is extremely difficult and based on the very subtle distinction between subcortical and weak cortical responses (American Congress of Rehabilitation Medicine, 1995; Pilon & Sullivan, 1996; Strauss, Ahwal, Day, & Shavelle, 2000).

Background EEG in coma usually shows severe slowing of the dominant rhythms. Coma variants with dominating theta or even alpha rhythms have been described as well. These relatively fast rhythms, however, do not indicate a higher level of vigilance or a better prognosis (Berkhoff, Donati, & Basetti, 2000; Kaplan, Genoud, Ho, & Jallon, 2000). PET demonstrates a depression of brain metabolism whose level is comparable with that during barbiturate anesthesia (Rudolf, 2000; Tommasino, Grana, Lucignani, Torri, & Fazio, 1995). In the vegetative state, the EEG is usually moderately slowed (4–6 Hz); the dominant delta-rhythm or extremely flat EEG are rarely observed, typically only in cases of anoxic origin. The decrement of metabolic activity in subcortical structures in the vegetative state is deeper than in sleep but less severe than in coma. In contrast, cortical metabolism may even be more strongly suppressed than in coma (Rudolf, 2000; Tommasino et al., 1995).

Early evoked potentials to simple stimuli in both coma and vegetative state can vary from normal through different degrees of suppression up to complete disappearance. In coma, the degree of intactness of the evoked potentials serves as a predictor of outcome (Kane, Butler, & Simpson, 2000; Kane et al., 1996). This is, however, not true for vegetative state (Zeitlhofer et al., 1991).

In coma and vegetative states, late components (100–500-ms poststimulus) of ERP to complex stimulus material such as semantic or syntactic mismatch are often absent. However, Kotchoubey, Lang, et al. (2001) found that even in completely nonresponsive states, 15% to 20% of patients show, for example, an N400 component to semantically incorrect endings or a P300 component to simple auditory target stimuli. However, absence of evoked brain responses to simple, automatic stimuli does not predict absence of evoked brain responses to complex stimuli, and vice versa, in coma and vegetative states (Fischer et al., 1999; Gott, Rabinovicz, & DiGiorgio, 1991; Mutschler et al., 1996). The presence of late components in ERP indicates intact cognitive processing of the presented material in cortical areas but does not prove conscious experience and control. The subjective state of these patients can be deduced only in those cases regaining consciousness after coma (Childs & Merger, 1996) or if these paralyzed patients learn to communicate with a brain–computer interface, as described in the *Biofeedback* section. Deep brain stimulation with electrodes implanted in the nonspecific thalamic nuclei or other parts of the distributed consciousness system (Dehaene, 2001)—described in the *Hypnosis* section—resulted in restoration of some degree of communicative abilities and conscious experience of previously unconscious cognitive processing (Cohadon & Richer, 1993). Any inferences of ASC in those states from ERP, EEG, or other brain-imaging methods need external validation through behavioral, psychological, or clinical criteria. Patients recovering from coma or vegetative state usually remain amnesic. At present, conclusions or judgments about the (altered) states of consciousness in coma, vegetative state, or locked-in-syndrome without such external validation are impossible.

Epilepsy

Cortical seizures with their typical pattern of paroxysmal activity are an excellent example of the tight connection between neuroelectric (pathological) changes and conscious experience: Location, extension, and intensity of the neurographic signs are correlated with the quality and intensity of the psychological event before, during, and after the seizures.

The common underlying neurophysiological principles of many different types of epileptic seizures are *hypersynchronizations* of extensive neuronal tissue. Loss of consciousness occurs only if large enough cortical tissue in critical areas is involved and the hypersynchronization causes interruption of normal functioning of the involved neuronal pool or deactivates structures involved in regulation of consciousness and attention (see Table 3). *Partial seizures* concern local areas of the brain and are excellent examples of the "modularity" of consciousness and the underlying brain mechanisms (for a review, see Niedermeyer & Lopes da Silva, 1999).

Dependent on the anatomical origin of the paroxysmal neuroelectric discharge, patients experience motor activity, sensory symptoms, or cognitive, emotional, or autonomic alterations: Particular seizures of the medial temporal lobe with the underlying hippocampal and other limbic structures such as the amygdala lead to characteristic and well-described ASC such as dreamy states, distortions of time sense (Bancaud, Brunet-Bourgin, Chauvel, & Halgren, 1994; Vuilleumier, Despland, Assal, & Regli, 1997), religious experience (Saver & Rabin, 1997), and altered affect (Tisher et al., 1993). Visual and auditory hallucinations are particularly frequent after discharges of the memory structures of the medial temporal lobe and the connected hippocampal and cortical regions. Stored memories are excited together with emotional responses in a structured or seemingly chaotic fashion (Bien et al., 2000; Brinciotti, Di Sabato, Matricardi, & Guidetti, 2000; Carmant et al., 1996; Gloor, 1990). Out-of-body experience and autoscopy (seeing one's body in extrapersonal space) are thought to be due to a paroxysmal dysfunction of the temporoparietal junction in a state of partially and briefly impaired consciousness (Blanke, Landis, Spinelli, & Seeck, 2004).

Conclusions

The multiple pathological processes that can result in various degrees of ASC may be viewed as impairing brain functions at different functional levels that seem to be hierarchically organized. Usually, loss of consciousness—for example, during coma—is a consequence of severely affected brain stem functions, whereas during vegetative states brain stem functions are preserved but most cortical functions are lost. On a higher cortical level, paroxysmal neuroelectric discharges (e.g., epileptic seizures) result in altered conscious experiences. The study of the waxing and waning of symptoms and the concomitant physiological changes shows that the normal stream of consciousness critically depends on integrated neural processes and functional clusters subserved by coherent neuronal networks, for example, through corticothalamic and cortico-cortico reentrant interactions. Whenever these integrative networks are interrupted—for example, by minor asynchrony or complete uncoupling—ASC are likely to occur. The findings on disease-induced ASC, at a first glance, support the notion of functional and neurobiological modularity. However, the dynamics of altered conscious processes and the content and context of consciousness require a distinct functional organization of integrative neuronal circuits whose nature is still far from being clearly understood (for a discussion, see Dehaene & Naccache, 2001).

Discussion

Phenomenology of ASC: A Four-Dimensional Descriptive System

Facing the variety of ASC, one easily feels lost in the plentitude of disparate and seemingly irreducible phenomena. The aim of phenomenology of ASC, as far as it serves science, is not to account for every tiny detail of experience but, rather, to introduce a reasonably simple reference system, a system of dimensions allowing for descriptive reduction of observed behavior or reported experience.

In the beginnings of scientific interest into ASC, authors constructed lists of basic dimensions or characteristics of ASC (Ludwig, 1966; Tart, 1975). In an attempt at synthesis of those earlier predecessors, Farthing (1992) ended up with no less than 14 dimensions, a rather eclectic listing of psychological functions and selected domains of experience; other authors proposed up to 26 dimensions (Pekala, 1991). For the purpose of this review, we propose a four-dimensional descriptive system that, as shown below, allows one to embed most of the ASC treated in this report. The dimensions were obtained by a synoptic overview of the experiential material reported from various ASC and a phenomenological reduction to their essential features; that is, they are not results of a factor analytic or clustering technique. First we want to briefly characterize the four dimensions, and then we apply the system to groups of ASC under study.

1. *Activation* in its broadest biological meaning refers to the readiness of an organism to interact with its physical or social environment. Activation is one of the most important dimensions in objective description of behavior, even in organisms to which we do not (or only hesitatingly) attribute consciousness. In subjective experience, activation is represented as being alert, awake, responsive, and ready to act and react; the dimension spans high arousal, excitement, and agitation as well as low arousal, relaxation, and inertia. Decrease of activation under a certain threshold is incompatible with awareness of reality and results under normal physiological conditions in sleep.

2. *Awareness span* refers to the variability of the contents available to attention and conscious processing. Awareness span ranges from narrow, focused attention directed at a singular content (e.g., in an intense mental activity) to broad, extended awareness embracing "all the things" in a single grasp (e.g., contemplating the horizon). Variability of awareness span is accessible to the subject and is reported mostly in post hoc, reflective evaluation.

3. *Self-awareness* refers to the other pole of the bipolar self–world structure of human experience. In a reflective attitude, all experience is "mine," that is, related to the subject's self. In the flow of immediate experience, however, the degree of self-reference may largely vary from "forgetting oneself" in absorption or exaltation to an intensified feeling of one's unique being, "I, here and now." Variability of self-awareness is also subjectively accessed and reported mostly in post hoc, reflective evaluation.

4. *Sensory dynamics* comprise the variety of changes in the sensory and perceptual component of subjective experience. With varying states of consciousness, sensation may be reduced (higher thresholds, anesthesia) or enhanced (lower thresholds, hyperesthesia); some ASC are characterized by a particular production of sensations and perceptions even without an adequate physical stimulus (e.g., synesthesia, dreams, hallucinations). The sensation component is partially accessible to physiological assessment (e.g., by sensory threshold measurements), but the most important changes in richness, vividness, structure, and contents of the perceptual component are revealed exclusively by subjects' reports.

These four dimensions are well anchored in everyday experience, and their definition does not require reference to any special or altered state of consciousness. On the contrary, peculiar characteristics of ASC, often considered to be their unique and irreducible features, can be easily translated into the four-dimensional system (see Table 2). For example, the often described "oceanic experience" (Dittrich et al., 1985) results primarily from expansion (+) of the awareness span with simultaneous reduction (–) of self-awareness, while the changes in other dimensions play an unspecific, modulating role: Activation may be unchanged or reduced (–) in deep relaxation, and sensory dynamics may be unaffected or moderately intensified (+).

Undoubtedly, other dimensions could also be useful in describing specific features of altered states. One might think of internally generated *cognitive processes* changing in a typical manner during some of the states listed in Table 2. Especially disease-induced altered conscious states like schizophrenia and epilepsy are characterized by severely impaired cognitive processes. The preceding reviews of spontaneously occurring and voluntarily induced ASC also describe a multitude of alterations with respect to the amount and the quality of cognitive processing. In view of the diversity of those changes and the many facets of cognitive processes—thinking, emotion, memory, imagery—an additional dimension of this type appears to be too complex to be rated on a single scale with adjustable anchor points and scale factors. At present, therefore, we favor to confine the descriptive system to four dimensions that allow a rather broad description. Obviously, if a specific ASC is under scrutiny, additional and more specific markers have to complement the four dimensions.

Table 2 contains the proposed assignments of ASC, classified by the induction methods, as they resulted from expertise given by the review. The table shows that most ASC can be unequivocally classified within the system. In some cases, the plus and minus signs may indicate variations in the course of induction and maintenance of the respective state. For example, within the ganzfeld-induced ASC (see *Sensory Homogenization*) we can distinguish "preparatory" and "productive" phases (Wackermann, Pütz, & Braeunig, 2002); the preparatory phase is characterized by widened awareness span, preserved self-awareness, and reduced sensory dynamics, whereas the productive phase features focused awareness span, usually reduced or absent self-awareness ("absorption"), and emerging hallucinatory sensory experience. Sensory homogenization thus effectuates alternating states with the signatures – + + – and – – – +.

The entries meditation, hypnosis, and biofeedback in Table 2, deserve a special mention in this context. The omnipresence of plus and minus signs in this group is no counterargument against the applicability of the four dimensions; rather, it reflects the variety of particular induction procedures and their intended effects. This can be exemplified by different meditation techniques: Activation is reduced in transcendental meditation but increased in

Table 2
Phenomenological Dimensions of Altered States of Consciousness

Induction method	Activation (+ aroused − relaxed)	Awareness span (+ wide − narrow)	Self-awareness (+ present − absent)	Sensory dynamics (+ increased − decreased)
Spontaneously occurring				
States of drowsiness	−	−	+/−	−
Daydreaming	−	−	+	+
Hypnagogic states	−	−	+	+
Sleep and dreaming	−	+	+	+
Near-death experiences	−	−	+	+
Physically and physiologically induced				
Extreme environmental conditions	+	−	+	+
Starvation and diet	+	−	+	−
Sexual activity and orgasm	+	−	−	−
Respiratory maneuvers	−	−	+	−
Psychologically induced				
Sensory deprivation	−	+	+/−	−
Sensory homogenization	−	+/−	+/−	+
Sensory overload	+	−	−	+
Rhythm-induced trance	+	+	−	+
Relaxation	−	−	+	−
Meditation	+/−	+/−	+/−	+/−
Hypnosis	+/−	+/−	+/−	+/−
Biofeedback	+/−	+/−	+/−	+/−
Disease induced				
Psychotic disorders	+/−	+/−	−	+/−
Coma and vegetative state	−	−	−	−
Epilepsy	+	−	−	+/−

tantric meditation; the awareness span is narrowed in concentrative meditation but widened in mindfulness meditation; self-awareness is reduced in states of meditative absorption *(samadhi)* whereas other meditation techniques cultivate a distanced, self-reflecting attitude; finally, sensory dynamics may also differ between meditation techniques depending on the object of meditation, be it a paradox riddle *(kôan)*, a syllable *(mantra)*, the subject's own breath, or a detailed visualization of Buddha's figure. It is thus impossible to specify unidirectional alterations for the category of meditation in its entirety, and this holds true for the diversity of states induced by biofeedback techniques or hypnotic procedures as well. This observation also presents a challenge for the future studies into ASC, namely, to differentiate, in terms of their phenomenology, the variety of ASC occurring within each of the broad categories defined by the induction methods. We believe that the proposed four-dimensional descriptive system provides a useful basis for such studies.

Of the four dimensions listed above, the activation dimension is nearest to the description in terms of physiology, by reference to unspecific activation systems in the brain, to autonomic nervous systems, and to the correlative changes in bodily processes in general. The other three dimensions may be related to central integrative and regulatory functions of brain subsystems (awareness span and self-awareness) or to specific sensory systems and higher level binding and regulatory subsystems (sensory dynamics). Singular dimensions of the proposed system can thus be linked to the organizational levels as specified in the hierarchical scheme presented in the concluding section of this report. Some of the underlying neurophysiological systems and mechanisms are discussed in the following sections.

Changes in Arousal Systems

ASC are obviously related to alterations of those brain systems responsible for the regulation of consciousness, arousal, and selective attention. While these systems were usually characterized as "unspecific," causing widespread excitatory changes in the cortex, more recently several specific subsystems serving circumscribed functions in the regulation of attention, wakefulness, and sleep were identified (for a review, see Dehaene, 2001). In Table 3 we provide a schematic summary of the functional brain systems involved in the regulation of attention and consciousness, listing also some of the disorders that result after lesions of these subsystems.

The limited capacity control system (LCCS) becomes active only if processing of new, complex, or vitally important information and voluntary decisions occur. The appearance of consciousness at a physiological level therefore consists of an increase in cortical complexity (Tononi & Edelman, 1998) and widespread reduction of cortical excitation thresholds regulated by the brain systems enumerated in Table 3. The subcortically mediated increase in excitation of forebrain structures requires a certain minimal anatomical extension and duration. Reentrant pathways particularly between thalamic and cortex guarantee reverberation of neuronal activity over a certain time period, usually longer than 100 ms, necessary for maintaining the mutual information exchange (Baars, 1988; Llinas, 2001). ASC may result from various deviations of inter- and intraregional neuronal information exchange of the LCCS and the connected brain modules; that is, dreamy states may result from excitation of posterior sensory cortical association areas without concomitant prefrontal activation of working memory enabling consistent planning, which results in hallucinations typical for active dreaming (Hobson, Pace-Schott, & Stickgold, 2000).

Functional Integration and Breakdown of Connectivity

ASC induced by a decrease of sensory input, homogenization, sensory overload, or strong rhythmic patterns of input are associated with a strong reduction in the naturally occurring range of variability in sensory input. Therefore, the reduction of sensory input seems to be an important element to induce ASC; for example, some methods use the narrowing of sensory input and attention as a core element for induction (e.g., hypnosis).

Table 3
Neuroanatomical Substrates of Attention and Arousal (the Limited Capacity Control System)

Neuroanatomical system	Function	Consequences of lesion
Prefrontal cortex (dorsolateral)	Working memory, comparison with stored contents	Lack of planning and self-control, short attention span
Orbitofrontal cortex	Motivational meaning	Pseudopsychopathy, apathy
Anterior cingulate cortex	Mobilization, error monitoring	Akinetic mutism (combined with extensive prefrontal lesion)
Inferior (right) parietal cortex	Disengagement of attention	Attentional neglect
Reticular and midline thalamus	Selective attention ("reentrant" corticothalamic oscillation)	Loss of attentional modulation and consciousness
Basal ganglia (striatum)	Modulation of cortical excitation thresholds	Over- or underselectivity of attention and motor behavior (i.e., schizophrenia)
Basal forebrain	Cholinergic modulation of cortical arousal and memory	Loss of consciousness and explicit memory (i.e., morbus Alzheimer)
Mesencephalic reticular formation	Cholinergic, glutamatergic and adrenergic arousal of the forebrain	Coma, vegetative state
Left frontal operculum and right anterior parietal cortex	"Mirror neurons," discrimination between self and others, self-awareness, empathy ("theory of mind")	Autism (lack of interest in others), psychopathy (sociopathy)
Ventromedial prefrontal cortex	Combining immediate goals with long-term goals, cost–benefit analysis for empathy system	Loss of planning
Cerebellum (cerebellar-frontal pathway)	Coordination of physical activity and cognitive operations with external stimuli	Autism (lack of cognitive coordination, focus on isolated stimuli)

Illusions or hallucinations are much more difficult to explain. Obviously, many different types of hallucinatory experience exist, each asking for a different neuroscientific explanation. Daydreaming and ganzfeld hallucinations are associated with simultaneous awareness of the imaginary nature of the experience. Hallucinations during dreaming and hypnosis can be recognized as such retrospectively, whereas schizophrenic patients insist on the reality of their hallucinated experiences. Brain-imaging experiments in schizophrenic individuals during active auditory hallucinations indicate the activation of a medial temporal lobe–basal ganglia–thalamic circuit in the absence of external stimulation. In contrast, hypnotically induced hallucinations are characterized by a dynamic dissociation between frontal and parietal connectivity.

Recent research on the question of how the brain binds together different features of internal or external stimuli into meaningful representations has suggested that such binding might be organized by synchronous neural activation within groups of cells with specialized functional properties. Whereas stimuli with low complexity are assumed to be represented by only a few of such cell assemblies with restricted topographical distribution, stimuli composed of many complex features are hypothesized to be represented by larger cell assemblies with widespread topographical organization. Since Hebb (1949), who first suggested such functional cell assemblies, a number of studies have shown that each cell assembly can be characterized by its own high-frequency oscillations. Among the carrier frequencies identified for such oscillations, activities within the gamma band have become the most prominent one and were demonstrated to be critical for normal conditions of attention, the ability of learning and memory formation, language, and meaningful motor behaviors. In contrast, a breakdown of the connectivity between large groups of cell assemblies was suggested to be a basis for hallucinatory states and states of illusion during schizophrenia, the emergence of hypnotic states, and the loss of consciousness induced by anesthesia. Such breakdown of coherent oscillations turns complex groups of cell assemblies into functionally independent units and seems to be associated with serious disturbances of stimulus representations and other cognitive and behavioral functions.

Fine Structure of Brain Functional States and States of Consciousness

The state of consciousness changes spontaneously over time, during development from birth to childhood to adulthood, during the circadian cycle, and in shorter near-periodicities. These changes imply a hierarchy of states of consciousness in terms of their characteristic duration and stability (Tart, 1975); for example, the sleep–wake cycle follows the circadian periodicity, and minor fluctuations of vigilance occur on a time scale of hours or minutes, whereas Wundt's "fluctuations of attention" (Woodworth & Schlosberg, 1954) are changes in the range of seconds. This time scale of hierarchically embedded states of consciousness may be extended to the subsecond range, as indicated by spatial analyses of brain electric fields.

Multichannel recordings of spontaneous or evoked brain electric fields can be transformed into series of instantaneous scalp field configurations, that is, momentary maps showing landscapes of different topographies. These brain field map series exhibit brief epochs of quasi-stable map topographies, separated by rapid, discontinuous changes. Accepting that the brain at each moment in time is in a particular state, and considering that different spatial configurations of the brain electric field must have been generated by different sets of active neurons, then, one should conclude that different brain field configurations indicate different states.

These brief brain states that occur in the subsecond range are called *microstates* to distinguish them from global brain *macrostates* with durations ranging from seconds to minutes. Average microstate durations in spontaneous EEG, identified by various segmentation procedures, have been within the range of 60–150 ms (Lehmann, Ozaki, & Pal, 1987; Pascual-Marqui, Michel, & Lehmann, 1995; Strik & Lehmann, 1993).

Microstates may be classified by their field topographies, compared between groups or states in terms of their mean duration and/or of the percentage of time covered. Topographies of spontaneously occurring microstates in normal individuals have differed for different mentation modes, thus suggesting that microstates might be building blocks of consciousness or, metaphorically, "atoms of thought" (Lehmann et al., 1998). Microstates have differed during maturation (Koenig et al., 2002); have differed in awake, drowsy, and REM states (Cantero, Atienza, Salas, & Gomez, 1999); have shown greater variability in schizophrenia (Merrin, Meek, Floyd, & Callaway, 1990); and have shown shortened duration, specifically for microstates of certain classes, in untreated, first-episode schizophrenics (Koenig et al., 1999; Koukkou, Lehmann, Strik, & Merlo, 1994; Lehmann et al., in press) and chronic schizophrenics (Strelets et al., 2003).

Mean duration and frequency of occurrence provide a first-order description of microstates; a higher order analysis may focus on the rules of concatenations of the "atoms," that is, their "syntax." Analyses of transitions between microstates of different classes have shown that transition probabilities are class dependent and have revealed asymmetries of transition probabilities between classes (Wackermann, Lehmann, Michel, & Strik, 1993). This indicates that sequences of microstates are not entirely random but follow certain probabilistic syntactic rules. Following the general interpretation of microstates as building blocks of consciousness, alterations of consciousness may reflect changes of microstate sequencing rules. Indeed, microstate syntax in untreated, first-episode schizophrenics has shown clear alteration, with some tendency to reversed sequencing among certain classes (Lehmann et al., in press).

Yet another approach to studies of the neural basis of states of consciousness has involved methods of nonlinear dynamics applied to brain electric activity (Pritchard, 1997) with bearing on consciousness-related topics, for example, differences between sleep stages (Röschke & Aldenhoff, 1991; cf. Achermann, Hartmann, Gunzinger, Guggenbühl, & Borbély, 1994) and increased dimensional complexity in schizophrenic individuals as compared with controls (Koukkou, Lehmann, Wackermann, Dvorak, & Henggeler, 1993; Saito et al., 1998). Although nonlinear complexity measures have been mostly calculated from one-dimensional time series derived from single scalp loci, these methods can be applied to the brain in its entirety, considering brain electric activity as a spatially distributed process (Babloyantz, 1989; see Dvorak, 1990, on global dimensional complexity). Various linear measures of covariance complexity of multidimensional brain electric data that are less computation intensive and easier to interpret have also been proposed (Palus, Dvorak, & David, 1990; Pézard et al., 1996; see Wackermann, 1996, on omega complexity).

Global measures of brain functional states are of particular interest for studies of consciousness, because consciousness involves the highest, integrative functions of the brain. The global complexity measure, omega, provides a single dimension onto which functional states of the whole brain can be mapped. Systematic variations of global omega complexity with sleep stages have been demonstrated (Szelenberger, Wackermann, Skalski, Niemcewicz, & Drojewski, 1996). However, brain states related to different states of consciousness may project to the same position on a one-dimensional continuum. Accordingly, a three-dimensional system of global descriptors—integral power (Σ), generalized frequency (Φ), and spatial complexity (Ω)—has been proposed, which allows a clear separation of sleep stages and indicates that at least two dimensions may be required to account for the variety of wakefulness–sleep transitions (Wackermann, 1999). These results have demonstrated applicability of the global brain state description for consciousness-related studies and have motivated their use in exploring other, more subtle alterations. For example, omega complexity as well as global dimensional complexity has been found to increase in schizophrenic patients versus controls (Saito et al., 1998).

Microstate analysis and multichannel EEG complexity analysis have much in common: They share the focus on the spatial aspect of brain functional states, they operate on the same data—that is, on sequences of scalp field maps interpreted as a series of momentary electrical brain states or as a trajectory in a multidimensional state space—and there is a one-to-one correspondence between basic notions of the two analytical approaches. Higher global spatial EEG complexity thus corresponds to a higher multiplicity of microstates, and both can be interpreted as a higher diversity of actually active brain electric generators involved in the corresponding state of consciousness. Indeed, convergent findings of microstate and complexity analyses in schizophrenia (Koenig et al., 1999; Koukkou et al., 1994; Merrin et al., 1990; Saito et al., 1998; Strelets et al., 2003) support this theoretical construct. Thus, microstate analysis and global complexity analysis seem to provide a unifying framework for assessment and interpretation of brain functional states underlying states of consciousness and their alterations.

Final Conclusion and Directions for Future Research

The variety of ASC as reported above points to the vulnerably and modifiability of brain dynamics. Consciousness depends critically on the proper functioning of several brain systems that may be impaired, for example, by damage to brain tissue, neurotransmitter imbalances, hypo- or hypersynchronization, disconnectivity in the firing of neuronal assemblies, and fluctuations in arousal. On the other hand, brain functioning may be modified by alterations in perceptual input as well as by the use of cognitive self-regulation strategies. The following hierarchical scheme (see Figure 1) summarizes the different levels at which brain functioning may be altered. (Table 4 shows that the different conditions and methods reviewed in this article produce ASC by affecting brain functioning on different levels.)

During the ordinary waking state, subjective reality is created continuously by processes in the brain. The maintenance of everyday consciousness requires intact brain tissue, metabolic homeostasis, a moderate level of arousal, a balanced interplay of inhibitory and excitatory networks, and midrange environmental conditions. As soon as one of these prerequisites for reliable assembly formation is lacking, alterations of consciousness are

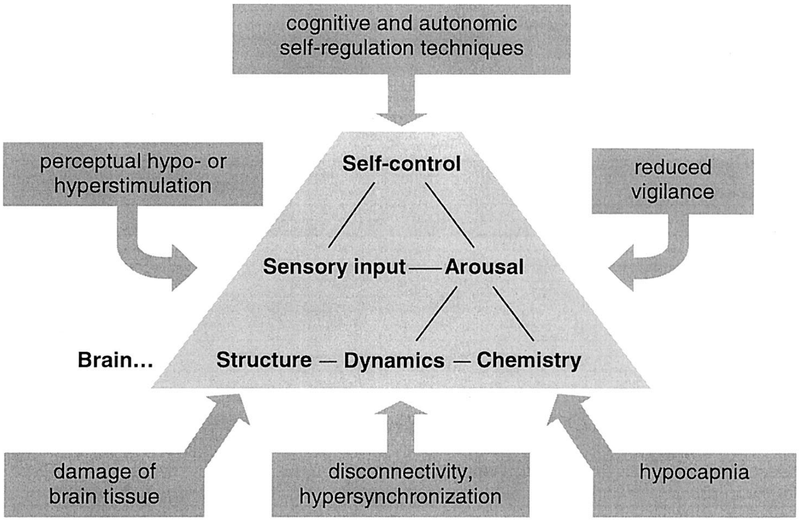

Figure 1. Different ways to induce altered states of consciousness. Lines within the pyramid emphasize the strong interdependence of the different levels.

likely to occur. Furthermore, by applying psychological procedures like hypnosis or meditation, it seems possible to voluntarily suppress or restrict the formation of assemblies, resulting in hypnotic analgesia or meditative states of sustained absorption.

To test the predictions made on phenomenological changes occurring during certain altered states (see Table 2), on the functional meaning of neuroanatomical systems (see Table 3), and on the levels of brain functioning provoked by the different induction methods (see Table 4), some methodological and conceptual approaches seem to be fruitful and may guide future research on ASC.

Methodological aspects. First, the dynamics of micro- and macrostates and the existence of local perceptual binding in the brain and quantification of local nonlinear dynamics can be inferred only by direct cortical recording with electrocorticograms (ECoG) or MEG. Both approaches allow the analysis of macropotentials, local field potentials, and oscillations undisturbed by the resistance of bone, cerebrospinal fluid, and skin, which act as filters, particularly for the high-frequency gamma band and electrical brain activity resulting from sulci, composing 60% of all cortical surface.

Table 4
Levels of Brain Functioning and the Induction of Altered States of Consciousness

Organizational level	Techniques, methods, and conditions
Self-control	Biofeedback, hypnosis, meditation, relaxation
Arousal	Drowsiness, hypnagogic states, sleep, dreaming
Sensory input, environment	Rhythmic stimulation, sensory deprivation, and homogenization
Neurochemical and metabolic processes	Hyperventilation, starvation and diet, near-death experiences
Brain dynamics	Epilepsy, psychotic disorders
Structural (brain tissue)	Coma

Second, a millimeter-scale localization of spontaneous and evoked electrocortical activity is mandatory to observe the subtle changes during most of the described ASC and to qualify the proposed ASC dimensions. ECoG recording is confined to the rare cases in which subdural or cortical placement of electrodes is ethically acceptable, such as preepileptic screening, recording during deep brain stimulation electrodes for the treatment of Parkinson's disease, dystonia, and chronic pain and brain tumor surgery. Substantial insight into ASC has already been provided from MEG recordings (Preissl et al., 2001; Tononi & Edelman, 1998), which avoid some but not all of the pitfalls of surface EEG. In addition, magnetic resonance-based noninvasive brain analysis, particularly of limbic and other subcortical regions (i.e., thalamus) that are not accessible to EEG, ECoG, and MEG recordings, when combined with simultaneous recording of EEG will provide complete new insight into the delicate cortico-subcortical interplay during ASC, as proposed above and as indicated in Table 3. Magnetic resonance spectroscopy, for example, allows neurochemical analysis of local brain areas during ASC, and diffusion tensor imaging may provide us with completely unknown anatomical connections between different, often far distant brain areas during the diverse ASC.

Third, the inclusion of anatomically confined lesions and disorders with ASC symptoms, such as those depicted in Table 3, may allow the independent manipulation of those brain areas thought to be responsible for a particular ASC as an independent variable coupled with observation of the ASC as a dependent variable. That is, reversible inactivation of left operculum with transcranial magnetic stimulation or transcranial direct current stimulation may allow one to specify the role of "mirror" neuronal fields for the experience of self-alienation comparable to those states found in the autistic disorder spectrum. Furthermore, operant conditioning (self-regulation and biofeedback) of local electromagnetic phenomena thought to underlie a particular ASC could be used to test the postulated correlations.

Conceptual aspects. First, the development of more sophisticated measures of brain activity and methods for the manipulation of distinct neuronal units must be complemented by the proper definition of the altered states under investigation. In the psychological approach to ASC, the notion of "state" is still laden with the heritage of descriptive psycho(patho)logy: States are conceived as syndromes or clusters of enumerable features. This is consistent with the strategy of access to the ASC via reports of subjective experience (first-person perspective). However, history shows that natural sciences largely benefited from (a) a transition from enumerative descriptions to measurable variables, (b) selection of minimal sets of variables needed to assess the state of the object under study, and (c) conceptualizing dynamics of state changes in terms of such abstract state spaces. We believe that the progress of our science lies along similar directions.

Second, future research becomes more complex by virtue of the fact that we must think in terms of two spaces, namely, that of states of consciousness and that of functional brain states; we refer to them as the *C-space* and the *B-space,* respectively. The four-dimensional descriptive system proposed may be considered a first step toward a construction of the C-space. Development and validation of measurement tools (questionnaires, inventories) should follow. There is no guarantee that the four dimensions represent a minimal set, but experience shows that state space approaches work best with reasonably low numbers of dimensions.

Third, concerning the construction of the B-space, our problem is not a lack of measurable data. Owing to the progress of modern neuroimaging methods, we have rather too much data. Novel data-analytical strategies are required to reduce the plenitude of momentary spatial distributions of brain activation to a limited number of "base modes." Following this reduction, a minimal number of state variables, constituting the reduced representation and thus assessing the global brain functional state, should be defined. The global descriptors of spatially distributed brain electric data mentioned in the section *Fine Structure of Brain Functional States and States of Consciousness* provide an example of this general strategy, which, however, has been confined to electrical brain fields data measured from the scalp surface.

Fourth, the syndromelike notion of *state,* abandoned above in favor of products of measurable dimensions, may reappear at a later stage redefined as compact regions of the state space; the narrative–descriptive variety of states of consciousness implicates such a partition of the C-space. Explorative partitioning of the B-space could be done in a similar way, using physiologically well-defined functional states as the external criterion.

Fifth, the challenge, then, can be described as mapping between the space of functional brain states and states of consciousness. The question of whether these mappings are to be conceptualized as two sides of a one-to-one, invertible isomorphism or rather one-to-many or many-to-many mappings should remain open. For practical reasons (noise, sources of variance unaccounted for, etc.), locations in both state spaces will always be "blurred," that is, determined with limited resolution, and thus the empirically established mappings between B and C will be necessarily of probabilistic nature. The virtue of the state space approach lies not in perfect one-to-one assignment but rather in assessment of general features of the coarse-grained mappings.

With increasing knowledge of the neural correlates of consciousness, the formerly strange and hard to explain phenomena of ASC become increasingly understandable as a natural consequence of the workings of the brain. This review of the current state of the art of scientific research on ASC clearly supports this perspective and hopefully stimulates further investigations into the psychobiology of ASC.

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