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Submitted: February 20, 2003

Revision submitted: October 2, 2003

Second Revision submitted: March 10, 2004

Third Revision submitted: June 28, 2004

## Abstract

The article reviews the current knowledge regarding altered states of consciousness (ASC) (a) occurring spontaneously (drowsiness, daydreaming, hypnagogia, sleep, dreaming and near-death-experiences), (b) evoked by physical and physiological stimulation (pressure, temperature, starvation/diet, sexual activity/orgasm, and respiratory maneuvers), (c) induced by psychological means (sensory deprivation/homogenization/overload, drumming, dancing, relaxation, meditation, hypnosis, and biofeedback), and (d) caused by diseases (psychosis, coma, vegetative state, and epilepsy). The emphasis is laid on psychological and neurobiological approaches. The phenomenological analysis of the multiple ASC resulted in four 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 in 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.

## Psychobiology of Altered States of Consciousness

### Introduction

Consciousness has come under renewed scientific investigation, both with respect to 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 of relatively uncharted processes, which are likely to be just as complex as those of so-called altered states of consciousness (ASC) which have currently 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 towards this end will be 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 which 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 argue 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 micro-seizures to be the biological bases for ecstatic and mystical states. In the same vein, Persinger (1983) claimed that mystical experiences are associated with transient micro-seizures in the temporal lobe in non-epileptic individuals. However, it is questionable if 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 where the data base and empirical evidence are strong enough to be discussed in detail.

In the past, some research 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 multi-channel 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 (see Footnote 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 multi-level-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, i.e., 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 (recent reviews of pharmacological induced ASC and affected neurotransmitter systems cf. Aghajanian & Marek, 1999; Parrott, 2001; Snyder, 1996; Vollenweider & Geyer, 2001).

The classification provided in Table 1 has been used to structure our review.

## 1 Spontaneously Occurring Altered States of Consciousness

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 will be addressed here: states of drowsiness (1.1), daydreaming (1.2), hypnagogic states (1.3) and sleep and dreaming (1.4). Among the spontaneously occurring ASC, near-death experiences are an infrequent and peculiar class of phenomena, detailed in section 1.5.

### *1.1 States of Drowsiness*

Variations of vigilance within the normal sleep—wake cycle usually do not induce ASC. Alterations of consciousness may occur with extreme sleep deprivation resulting in short episodes of immediate sleep onset („micro-sleep”; Oswald, 1962) or „amnesic automatic behaviour” (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/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 (EEG, electro-oculography, 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, reduced „blinks” (Morris & Mitler, 1996) 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 multi-channel 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 due to varying concepts like activation continuum (Lindsley, 1960), wakefulness, alertness, vigilance (Head, 1923; cf. Davies & Tune, 1970; Ulrich & Gschwilm, 1988; Weinberg & Harper, 1993) or, sleepiness and drowsiness. Drowsiness states open ways to so-called „hypnagogic states” at sleep onset, which are treated below (section 1.3) as a special, stand-alone class of ASC.

## 1.2 *Daydreaming*

Daydreaming refers to spontaneous, subjective experiences in a no-task, no-stimulus, no-response situation (see also 1.3 on hypnagogic states and 3.1 on 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 REM dreams; e.g., 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’ (1890) „stream of thought“ concept, and predominantly reports phenomenology, taxonomy and psychological/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 has revealed correlations between distinctive features in EEG spectra and cognition styles (Lehmann, Grass, & Meier, 1995). 120 EEG spectral (power) variables and 20 cognition/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 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, while 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 3.1 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 and 30 s, however, the basic units of mentation processes were estimated to be well in the sub-second 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-homogenous, 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, i.e. their rules of concatenations.

### 1.3 *Hypnagogic States*

Hypnagogic states are transient states of decreased wakefulness characterized by short episodes of dream-like sensory experience. These phenomena were first described by J. Müller (1826) as “fantastic visual phenomena” occurring usually, but not exclusively, at sleep onset. Maury (1848) coined for them the term “hypnagogic”, from Greek *hypnos* = sleep, *agogo* = I bring. Schacter (1976) described them as “dreamlets”. Subjects usually report short visual percepts like faces, landscapes and natural or social scenes which may or may not be related to previous day-time experience. These percepts may be of pseudo-hallucinatory (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. 1.4). 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 day-time 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, Hayashi, & Morikawa, 1994). The prevalence for frequent hypnagogic states is estimated at 37% (Ohayon, Priest, Caulet, & Guilleminault, 1996). Behavioral correlates are sparse, e.g. 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 dream-like imagery and drop-offs in alpha-EEG-activity was first noticed by Davis, Davis, Loomis, Harvey, and Hobart (1937). By definition, hypnagogic states are related to sleep onset, i.e. sleep stage 1 according to Rechtschaffen and Kales (1968), but may occur even with pre-sleep 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 non-emotional visual and/or auditory impressions of varying complexity were reported which 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, Grass, & Meier, 1995). Systematic comparisons of hypnagogic phenomena with perceptual phenomena that were observed with reduced sensory input (cf. section 3.1.b, „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.

#### *1.4 Sleep and Dreaming*

Dreaming which is not restricted to rapid-eye-movement (REM) sleep, but has been found to take place in all sleep stages, represents an altered state of consciousness, 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 meta-cognition are reduced, while the emphasis is on the here-and-now. A virtual sense of reality (except for the rare category of lucid dreams, see below), and a predominant ego involvement are the only continuous features of dreaming, while all 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 employed 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 (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 (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 micro-awakenings — 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 has reviewed 40 years of dream research, and he comes 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, Mazzota, 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 occipito-temporal 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 (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, Balkin, Wesensten, Gwadry, Carson, Varga, Baldwin, Belenky, & Herscovitch, 1998). A detailed discussion of the psychophysiology of sleeping and dreaming research was recently published in Behavioral and Brain Sciences (Special Issue, 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 on-line, but only retrospectively while awake. Due 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.

### *1.5 Near-death Experiences*

The typical core elements of near-death experiences include: (i) a feeling of peacefulness and well-being, (ii) a separation from the body (out-of-body experience), (iii) a dark tunnel experience, (iv) a brilliant light associated with mystical feelings of love and union, and (v) 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 percent 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. illness, accident, suicide, 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 hypothesis 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, septo-hippocampal 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). Since 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 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, 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.

## 2 Physically and Physiologically Induced Altered States of Consciousness

Besides pharmacological induction, there is a wide variety of physical and physiological methods and maneuvers which 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 are extreme environmental conditions (2.1) and starvation (2.2). In contrast to these possibly life-threatening environmental and behavioral conditions, there are other physiological conditions which may result in altered states of consciousness, such as sexual activity/orgasm (2.3), described by the French expression „la petite mort”, and forced respiratory maneuvers (2.4).

### 2.1 *Extreme Environmental Conditions*

Behaving in extreme environments has been reported anecdotally to induce altered states of consciousness including auditory or visual hallucinations, somesthetic illusions or states of trance. However, while most of these reports have captured large public interest (i.e., Messner, 2001), only 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 like 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 deserts, or exposure to microgravity during space flights.

In one of the few empirical studies (Brugger, Regard, Landis, & Oelz, 1999) the incidence and the circumstances of altered states of consciousness were investigated retrospectively by structured interview on the effects of exposure to altitudes above 8500 m without supplementary oxygen in eight world-class climbers. Additionally, subjects were examined by neuropsychological tests and electroencephalographic and magnetic resonance imaging 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 6000 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 suggests 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).

While 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 exposure to hyperbaric conditions is associated with the emergence of altered states of consciousness or different cognitive and behavioral dysfunctions. While 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, Martinez, Lemaire, Bisson, deMendoza, & Therme, 1997; Bast & Pettersen, 1999). The emergence of altered states of consciousness 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) which are inhaled by divers while being in deep water for long periods of time (Tetzlaff, Friege, Hutzelmann, Reuter, Hoell, & Leplow, 1999).

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

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. While 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 (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 behaviour 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 altered states of consciousness are common phenomena of cosmonauts or astronauts (Carr, 1991) during space flights. Again, it is assumed that such responses are paroxysmal consequences of primary diseases or of sudden illnesses (Dudley Rowley, 1997).

## 2.2 *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 altered states of consciousness as expressed by an attentional bias for food stimuli, disturbed body image, illusions or hallucinations.

Based on 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 have been requested to name the color of words belonging to different categories (food, body image vs. neutral in relation to these categories) but not to attend to the content. It has been 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, i.e. 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, Goldman, Biver, De Maertelaer, Wikler, Damhaut, & Lotstra, 1997; Delvenne, Goldman, De Maertelaer, Simon, Luxen, & Lotstra, 1996). 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, Ettrich, Assmann, Dahne, Krause, Busse, & Gertz, 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.

### 2.3 *Sexual Activity/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 Tallafiero (1954) reported rapid low voltage activity during early stages of sexual arousal which 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. 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 to the left hemisphere during sexual arousal induced by imagery. The results were replicated by 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, Kuikka, Kupila, Vainio, Airaksinen, Eronen, Hallikainen, Paanila, and Kinnunen (1994) confirmed the results of lateralized right hemispheric activation during orgasm with single positron emission computed tomography (SPECT). They found increased regional cerebral blood flow (rCBF) at the right prefrontal cortex.

Neurosurgery and brain lesions after injury has revealed the involvement of frontal and temporal areas in the inhibitory control of sexual behavior (Freeman, 1973; Terzian and Dalle Ore, 1955) and septal nuclei in the control of sexual arousal (Gorman & Cummings, 1992). Redouté, Stoléru, Grégoire, Costes, Cinotti, Lavenne 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 end-path” 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 & McLean, 1964). Likewise, Rauch, Shin, Dougherty, Alpert, Orr, Lasko 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 altered state of consciousness not comparable to any other psychophysiological states.

#### 2.4 *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 breath and exhaling slowly. The method of slow diaphragmatic breathing and paced respiration is also a procedure which 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 upon increases in  $p\text{CO}_2$ , 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<sub>2</sub>-enriched breathing air mixture. Meduna (1950) reported that hypercapnia may result in typical near-death experiences (see section 1.5), such as bodily detachment and the perception of being drawn towards 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<sub>2</sub>-enriched breathing air mixture did not lead to slow-wave EEG and concomitant experiences of obnubilation, depersonalisation, and derealization. These differences may largely be traced back to the varying amount and duration of inhaling CO<sub>2</sub>-enriched air mixture.

Breathing has also been manipulated by techniques which lead to hypocapnia, such as shamanism practices, ritual dances, holotropic breathing (Grof, 1976), or 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). 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 percent. 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<sub>2</sub> 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<sub>2</sub>/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 altered states of consciousness 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 which is an important constituent of yogic (Pranayama) breathing exercises, i.e. 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-minutes 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 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.

## 3 Psychologically Induced Altered States of Consciousness

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.



### 3.1 *Sensory Deprivation, Homogenization and Overload*

#### 3.1.a *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 where environmental stimulation is not blocked totally but limited in terms of its variability, patterning, meaningfulness and/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 Suedfeld, 1980; Atkinson, 1993). Autobiographic life episodes were retrieved more intensely and recalled more pleasantly after

participation in a restricted stimulation treatment as compared to 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 (ECT) showed less severe memory loss when exposed to restricted stimulation immediately after shock therapy as compared to a condition where 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 to 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 towards 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 of the studies (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 non-dynamical and non-psychopathological 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), 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 kinaesthetic acuity (Zubek, 1969) could not be replicated (Suedfeld, 1980).

The same is true for time perception. For example, confinement of subjects for 72 hours did not affect subject's estimation of time spent in an isolation chamber independently of behavioral activities of the subjects. Over- or underestimation of time was associated with periods of higher behavioral activity while during periods of fewer time estimation errors, behavioral activities 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 extend changes of perception during restricted environmental stimulation relate to different neural activities of the human brain has not been established systematically. While EEG studies during restricted environmental stimulation have shown changes of

alpha-, beta-, and theta-band activities in general (see Zubek, 1969, Suedfeld, 1980) systematic studies on brain electrical concomitants of visual, auditory, and/or other sensory changes, illusions, and hallucinations are widely lacking. ASC were only seen 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 may arise while exposed to restricted stimulation environments (Zubek, 1969). Whether ASC are a common consequence of sensory deprivation is not settled by systematic empirical research.

### *3.1.b Sensory homogenization („ganzfeld“)*

Ganzfeld is a technical term for an unstructured, perfectly homogeneous perceptual, usually visual field (Avant, 1965; Wertheimer 1923). A longer exposure (from minutes to few tens of minutes) to visual (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, dream-like experience. As for subjective experience, visual imagery is most frequently reported, while 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 1.3). It was hypothesized that ganzfeld induces a kind of „experimental hypnagogic state“ (Braud, Wood, & Braud, 1975; Schacter 1976), i.e. a decrease of vigilance (see 1.1). Little is to be said about behavioral correlates: due to 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 (for examples see Honorton, Berger, Varvoglis, Quant, Derr, Schechter, & Ferrari, 1990). This may be partly due to the unusual, dream-like nature of ganzfeld experience, not necessarily due to impairment of cognitive functions. It was

assumed (Honorton & Harper, 1974; Parker, 1975) that ganzfeld induces a state favorable to „extra-sensory 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 only little affected by ganzfeld; verbal estimates of elapsed time intervals (5 – 15 min) showed a tendency to underestimate comparable with the waking state (Wackermann, Pütz, & Miener, 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. Intra-individual comparisons against no-imagery EEG revealed mostly tri-phasic courses, consisting of (1) initial alpha-increase, (2) burst of accelerated alpha-2 activity (10 – 12 Hz), and (3) deceleration and reduction of alpha-rhythm and undulating increase of beta-2 (18 – 21 Hz) and beta-3 (21 – 30 Hz) power, indicating a transition from relaxation to outwards directed and fluctuating attention and finally preparation for the mentation report (Wackermann, Pütz, & Braeunig, 2002).

### *3.1.c Sensory overload*

There is a long tradition of attempting to induce altered states of consciousness 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 pre-pulse 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, including schizophrenia, intensive care unit syndrome, autism, and use of hallucinogens.

In schizophrenia (see section 4.1) 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 & Stark, 1973, Ludwig, 1972). 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 which 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 effects on both 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 over-stimulation.

### 3.2 *Rhythm-induced Trance (Drumming, Dancing)*

Drumming and dancing have been practiced since ancient times to induce altered states and are still common today. They may result in trance-like states which are 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 to 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 (1980), 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 to 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 also 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 but also they 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, reduced muscular reflexes — resemble typical features of trance states. In order to investigate if 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  $-6$  degrees head-down and  $+12$  degrees 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 respectively tilting 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 non-responders. 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 also 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.

### 3.3 *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: (i) focusing: the ability to maintain focus on, and return attention to simple stimuli (acoustic or visual) for an extended period of time; (ii) passivity: the ability to refrain from goal-directed and analytic thoughts, and (iii) 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 sympatho-adrenergic 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. In so far 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). Jacobs and his co-workers (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 and collaborators (2001b) investigated the specific engagement of different brain regions during hypnosis-based suggestion of relaxation compared to suggestion of negative emotion, such as anxiety. Relaxation showed maximally stronger activity compared to anxiety in the left superior temporal gyrus (Brodmann area 22). During the two induced emotional states brain activity shifted to the right hemisphere in the fronto-temporal regions during negative compared with positive emotions (relaxation). The excitatory frequency EEG band of beta-2 (18.5 – 21 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 sympatho-adrenergic 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) have 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 (significant EEG signs: K-complex, 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 of making new experiences which are similar to those described for hypnagogic states (see section 1.3). 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 these occur they are treated as tolerable side effects. In this sense, relaxation techniques are helpful and indispensable adjuncts in the realm of ASC.

### *3.4 Meditation*

There is a great variety of meditation techniques which 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. The instructions, how to meditate, again 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 (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 non-specific 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 participants that have undertaken meditation for periods longer than three years with those practicing for less than six months has shown a difference in slow wave theta activity (Aftanas & Golocheikine, 2001) similar to earlier findings (Herbert & 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 pre-frontal

and the posterior association cortex, peaking in the left pre-frontal 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 pre-frontal 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 & Cardena, 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, Jeanmonod, Gianotti, and Pizzagalli (2001) investigated an advanced subject, 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, Bush, Gollup, Fricchione, Khalsa, and Benson (2000) conceptualized meditation as voluntary regulation of attention. Their subjects, who had practiced a breathing meditation for many years, were trained to meditate during functional magnetic resonance imaging (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, SPECT), 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 altered states of consciousness through the intentional self-regulation of attention.

### 3.5 *Hypnosis*

After 200 years of inquiry there is still great controversy over how hypnosis should be defined. Throughout its history the field has divided between those who evoke distinctive psychological processes and those who appeal to the ordinary processes which underlie everyday behavior. The altered state view taken in the present paper 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, or 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, though 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 (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 last 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 utilized 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, e.g. higher power in the theta frequency band in some studies, higher gamma power over the right hemisphere, higher Global Dimensional Complexity, all for high-susceptible subjects (for overview and recent results, see Isotani, Lehmann, Pascual-Marqui, Kochi, Wackermann, Saito, Yagyu, Kinoshita, Sasada, 2001a). However, until now

no neurophysiological measure or set of measures is able to reliably categorize data as obtained from hypnotized or non-hypnotized 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, e.g. emotions, postures, relaxation etc. (e.g. Isotani, Tanaka, Lehmann, Pascual Marqui, Kochi, Saito, Yagyu, Kinoshita, Sasada, 2001b).

Gruzelier (2000) has consistently advocated the view of hypnosis as a form of frontal inhibition for the last decade. 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 participants 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 subject's pain ratings in the control condition. This relationship remained unchanged by hypnosis for the participants 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, Trippe, Özcan, Weiss, Hecht, and Miltner (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 to the control condition but significantly smaller amplitudes of the late laser-evoked brain potential components during distraction as compared to 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 to 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 (Miller & Bowers, 1993; Hilgard & Hilgard, 1983) 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 breakdown of communication between subunits within the brain responsible for the formation of conscious experience (see section 5.3).

### 3.6 *Biofeedback*

Contemporary research supports the view that biofeedback and instrumental learning of neuronal activity is a promising non-invasive 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. There are various methods which 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 on-line 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  $\mu$ -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) postulate 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 and 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 while 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, 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, Egner, Cooper, Compton, Neilands, Sheri & Gruzelier, 2003) and attention (Egner & Gruzelier, 2004).

Another EEG parameter are 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, Elbert, Rockstroh et al., 1991). Thus, it was obvious to utilize 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 which resulted in a significant decrease of seizure rate (Kotchoubey, Schneider, Strehl et al., 1996; Kotchoubey, Strehl, Holzapfel et al., 1999; Kotchoubey, Strehl, Uhlmann et al., 2001; Rockstroh, Elbert, Birbaumer et al., 1993).

Moreover, the self-regulation of SCP can also be utilized for brain-computer communication. It may be needed for patients suffering from neurologic diseases leading to total motor paralysis caused by amyotrophic lateral sclerosis 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, i.e. by shifts in SCPs’ negativity. Birbaumer and his group have developed a Thought Translation Device and a training procedure which enables ALS-patients, 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, which show that the patients benefited by learned self-control of EEG parameter as EEG mechanisms underlying psychopathological and neurological disorders are understood in a better way. 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 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 (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 and Gruzelier, 2001; 2004; Vernon, Egner, Cooper Compton, Neilands, Sheri & Gruzelier, 2003). If EEG/MEG reflects ASC as discussed in this paper, learning to induce those EEG/MEG patterns underlying ASC should lead to those states.

### *Conclusions*

There is a huge body of literature linking altered states of consciousness induced by psychological induction procedures to changes in brain activity. While 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.

#### 4 Disease Induced ASC

There are numerous pathological processes which 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 towards clouding of consciousness, obnubilation, somnolence, sopor and coma. Regional brain lesions as well as high-level deafferentation and deafferentation (e.g. through a spinal cord injury or amyotrophic lateral sclerosis) are not reviewed here, because they typically result in a loss of circumscribed functions without disturbing consciousness in general. Nevertheless, the interest in the psychological concomitants e.g. of the so-called locked-in syndrome has increased in the last few years and new devices have been developed that enable the communication with these patients (Birbaumer, Ghanayim, Hinterberger et al., 1999). There exist many other degenerative, developmental and organic brain diseases that are accompanied by alterations of consciousness (e.g. Alzheimer disease, Morbus Parkinson, dementia with Lewy bodies, frontotemporal dementia). Although these phenomenological changes have been reported frequently they have only rarely been investigated systematically with respect to the interaction between subjective experiences and specific brain malfunctions. Due to this scarcity of empirical evidence these brain diseases were not reviewed here.

##### *4.1 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, Buechel, Whalley, Frith, Friston, & Johnstone, 2002). Germane to this approach is the

evidence that patients with meta-chromatic 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 NMDA glutamatergic transmission, produces positive psychotic symptoms (Thornberg & Saklad, 1996). Historically the disconnection concept guided research into the nature of interhemispheric connection in schizophrenia based on 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 thalamo-cortical circuits. Considering firstly 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 non-specific 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 pseudo-somatic 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 cortico-thalamic and cortico-cortico re-entrant 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 was 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, 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 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 which 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 and 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,b; Oke & Adams, 1987). Such anomalies include disturbances of sensory processing, sensory gating and magnocellular functions; of perceptual aberrations, 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 review see Gruzelier, 1999b; Berendt & Young, 2003) and to truncated microstates (see section 5.4).

#### 4.2 *Coma, 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 event-related brain potentials (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 non-responsiveness. Several scales have been developed in order 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 supposed 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 conscious 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, Curry, Rowlands, Minara, Lewis, Moss et al., 1996). This is, however, not true for vegetative state (Zeitlhofer, Steiner, Oder, Obergottsberger, Mayr & Deecke, 1991).

In coma and vegetative states late components (100 – 500 ms post-stimulus) of event-related potentials to complex stimulus material such as semantic or syntactic mismatch are often absent. However, Kotchoubey, Lang, Baales et al. (2001) found that even in completely non-responsive states 15 to 20 % of patients show for example an N400 component to semantically incorrect endings or a P300 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, Morlet, Bouchet, Luaute, Jourdan, & Salord, 1999; Gott, Rabinovicz, & DiGiorgio, 1991;

Mutschler, Chaumeil, Marcoux, Wioland, Tempe, & Kurtz, 1996). The presence of late components in ERPs 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 only be deduced 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 3.6. Deep brain stimulation with electrodes implanted in the non-specific thalamic nuclei or other parts of the distributed consciousness-system (Dehaene, 2001) — described in 5.2 — 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 ERPs, EEG or other brain imaging methods need external validation through behavior, 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.

#### 4.3 *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 *hyper-synchronizations* of extensive neuronal tissue. Loss of consciousness occurs only if large enough cortical tissue in critical areas is involved and the hyper-synchronization causes interruption of normal functioning of the involved neuronal pool or deactivates structures involved in regulation of consciousness and attention (see Table 3 in section 5.2). *Partial seizures* concern local areas of the brain and are excellent examples

of the „modularity” of consciousness and the underlying brain mechanisms (for review see Niedermeyer & Lopes da Silva, 1999).

Dependent upon the anatomical origin of the paroxysmal neuroelectric discharge patients experience motor activity, sensory symptoms, 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, 1998) and altered affect (Tisher, Holzer, Greenberg, Benjamin, Devinsky, & Bear, 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, Benninger, Urbach, Schramm, Kurthen, & Elger, 2000; Brinciotti, Di Sabato, Matricardi & Guidetti, 2000; Carmant, Carrazana, Kramer, Helmers, Holmes, Black 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 temporo-parietal junction in a state of partially and briefly impaired consciousness (Blanke, Landis, Spinelli & Seeck, 2004).

### *Conclusions*

The multiple pathological processes which can result in various degrees of ASC may be viewed as impairing brain functions at different functional levels which seem to be hierarchically organized. Usually, loss of consciousness , e.g. 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 neuroelectrical 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, e.g. through cortico-thalamic and cortico-cortico reentrant interactions. Whenever these integrative networks are interrupted, e.g. 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, 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 discussion: see Dehaene & Naccache, 2001).

## 5 Discussion

### 5.1 *Phenomenology of ASC: 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 attempt at synthesis of those earlier predecessors, Farthing (1992) ended up with no less than fourteen dimensions, a rather eclectic listing of psychological functions and selected domains of experience; other authors proposed up to twenty six dimensions (Pekala, 1991). For the purpose of this review we propose a four-dimensional descriptive system which, 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; i.e., they are not results of a factor-analytic or clustering technique. First we want to briefly characterize the four dimensions, and then apply the system to groups of ASC under study.

(i) *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, wake, responsive, ready to act and re-act; the dimension spans high arousal, excitement, 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.

(ii) *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 reported mostly in post hoc, reflective evaluation.

(iii) *Self-awareness* refers to the other pole of the bipolar self-world structure of human experience. In a reflective attitude, all experience is „mine”, i.e., 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.

(iv) *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 (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. For example, the often described „oceanic experience” (Dittrich, von Arx, & Straub, 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, 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 +/- signs may indicate variations in the course of induction and maintenance of the respective state. For example, within the ganzfeld-induced ASC (3.1b) 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, while 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 signatures  $- + + -$  and  $- - - +$ .

Entries 3.4–6 in Table 2, Meditation, Hypnosis and Biofeedback, deserve a special mention in this context. The omnipresence of +/- signs in this group is no counter-argument 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 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) while 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 sub-systems (sensory dynamics). Singular dimensions of the proposed system can thus be linked to the organizational levels as specified in the hierarchic scheme presented in the concluding section of this report. Some of the underlying neurophysiological systems and mechanisms are discussed in the following sections.

## 5.2 *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 after lesions of these subsystems.

The 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. Re-entrant 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: i.e. 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).

### 5.3 *Functional Integration and Breakdown of Connectivity*

ASC induced by a decrease of sensory input (1.1. – 1.5.), homogenization (3.1.b), sensory overload (see 3.1.c), or strong rhythmic patterns of input (3.2., partly 2.4.) 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, e.g. some methods use the narrowing of sensory input and attention as a core element for induction (e.g. hypnosis).

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, while schizophrenic patients insist on the reality of their hallucinated experiences. Brain imaging experiments in schizophrenics during active auditory hallucinations indicate the activation of a medial temporal lobe-basal ganglia-thalamic circuit in the absence of external stimulation. On the other hand hypnotically induced hallucinations are characterized by a dynamic dissociation between frontal and parietal connectivity.

Recent research on the question 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. While 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 wide-spread topographical organization. Since Hebb (1949), who first suggested such functional cell assemblies, a number of studies has 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.

#### 5.4 *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); e.g. the sleep—wake cycle follows the circadian periodicity, 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 sub-second range, as indicated by spatial analyses of brain electrical fields.

Multi-channel recordings of spontaneous or evoked brain electric fields can be transformed into series of instantaneous scalp field configurations, i.e. 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 neurones, then, different brain field configurations indicate different states.

These brief brain states that occur in the sub-second 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 normals 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). These have differed during maturation (Koenig, Prichep, Lehmann et al., 2002), in awake, drowsy and REM states (Cantero, Atienza, Salas, & Gomez, 1999), have shown greater variability in schizophrenia (Merrin, Meek, Floyed, & Callaway, 1990) and shortened duration, specifically for microstates of certain classes, in untreated, first episode schizophrenics (Koenig, Lehmann, Merlo, Kochi, Hell, & Koukkou, 1999; Koukkou, Lehmann, Strik, & Merlo, 1994; Lehmann, Faber, Galderisi, Herrmann, Kinoshita, Koukkou, et al., in press) and chronic schizophrenics (Strelets, Faber, Golikova, Novototsky-Vlasov, Koenig, Guinotti, Gruzelier & Lehmann, 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”, i.e., their „syntax”. Analyses of transitions between microstates of different classes have shown that transition probabilities are class-dependent and 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 non-linear dynamics applied to brain electrical activity (Pritchard, 1997) with bearing on consciousness-related topics, e.g. differences between sleep stages (Röschke

& Aldenhoff, 1991; cf. Achermann, Hartmann, Gunzinger, Guggenbühl, & Borbély, 1994), and increased dimensional complexity in schizophrenia compared to controls (Koukkou, Lehmann, Wackermann, Dvorak, & Henggeler, 1993; Saito, Kuginuki, Yagyu et al., 1998). While non-linear 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; Dvorak 1990: global dimensional complexity, GDC). Various linear measures of covariance complexity of multi-dimensional brain electrical data that are less computation-intensive and easier to interpret have also been proposed (Palus, Dvorak, & David, 1990; Pézard, Nadrino, Renault et al., 1996; Wackermann, 1996:  $\Omega$ -complexity).

Global measures of brain functional states are of particular interest for studies of consciousness, since 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 ( $\Sigma$ ), generalized frequency ( $\Phi$ ), and spatial complexity ( $\Omega$ ) 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 motivated their use in exploring other, more subtle alterations. For example,  $\Omega$ -complexity as well as GDC has been found to increase in schizophrenic patients vs. controls (Saito et al., 1998).

Microstate analysis and multi-channel 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, i.e., on sequences of scalp field maps interpreted as a series of momentary electrical brain states or as a trajectory in a multi-dimensional 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 electrical 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.

### 5.5 *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, e.g. by damage to brain tissue, neurotransmitter imbalances, hypo- or hyper-synchronization, 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 employing cognitive self-regulation strategies. The following hierarchical scheme (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 mid-range environmental conditions. As soon as one of these prerequisites for reliable assembly formation is lacking, alterations of consciousness are 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.

In order 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 non-linear dynamics can only be inferred by direct cortical recording with electrocorticograms (ECoG) and/or magnetoencephalography (MEG). Both approaches allow the analysis of macropotentials, local field potentials (LFP), 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, comprising 60% of all cortical surface.

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 where subdural or cortical placement of electrodes is ethically acceptable such as pre-epileptic

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 been already provided from MEG recordings (Preissl, Flor, Lutzenberger, Duffner, Freudenstein, Grote & Birbaumer, 2001; Tononi & Edelman, 1998) which avoid some but not all the pitfalls of surface EEG. In addition, MR-based non-invasive brain analysis, particularly of limbic and other subcortical regions (i.e. thalamus) which 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 indicated in Table 3. MR-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: i.e. reversible inactivation of left operculum with transcranial magnetic stimulation or transcranial DC-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 electro-magnetic 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 has to 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 have to think in terms of two spaces, namely that of states of consciousness and that of functional brain states; we will refer to them as C-space and the B-space, respectively.

The four-dimensional descriptive system proposed in section 5.1 may be considered a first step towards 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. Due 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, comprising the reduced representation, and thus assessing the global brain functional state, should be defined. The global descriptors of spatially distributed brain electrical data mentioned in section 5.4 provide an example of this general strategy which, however, has been confined only to electrical brain fields data measured from the scalp surface.

Fourth, the syndrome-like 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 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’, i.e. 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 altered states of consciousness.

## References

- Abraini, J. H. (1995). Evidence for inert gas narcosis mechanisms in the occurrence of psychotic-like episodes at pressure environment. *Neuroreport*, *6*(17), 2435–2439.
- Abraini, J. H., Martinez, E., Lemaire, C., Bisson, T., deMendoza, J. L. J., & Therme, P. (1997). Anxiety, sensorimotor and cognitive performance during a hydrogen-oxygen dive and long-term confinement in a pressure chamber. *Journal of Environmental Psychology*, *17*(2), 157–164.
- Achermann, P., Hartmann, R., Gunzinger, A., Guggenbühl, W., & Borbély, A. A. (1994). Is the EEG generated by a chaotic attractor? Dimension analysis of all-night sleep EEG. *Journal of Sleep Research*, *3*, 1.
- Aftanas, L. I., & Golocheikine, S. A. (2001). Human anterior and frontal midline theta and lower alpha reflect emotionally positive state and internalised attention: High-resolution EEG investigation of meditation. *Neuroscience Letters*, *310*, 57–60.
- Aftanas, L. I., Varlamov, A. A., Pavlov, S. V., Makhnev, V. P., & Reva, N. V. (2001). Affective picture processing: Event-related synchronisation within individually defined human theta band is modulated by valence dimension. *Neuroscience Letters*, *303*, 115–118.
- Aghajanian, G. K. & Marek, G. J. (1999). Serotonin and hallucinogens. *Neuropsychopharmacology*, *21*(2), S16–S23.
- American Congress of Rehabilitation Medicine (1995). Recommendations for use of uniform nomenclature pertinent to patients with severe alterations in consciousness. *Archives of Physical Medicine and Rehabilitation*, *76*, 205–209.
- American Psychiatric Association (1994). *Diagnostic and statistical manual of mental disorders (4<sup>th</sup> ed.)*. Washington, DC: American Psychiatric Association.

- American Sleep Disorders Association (1990). *International classification of Sleep disorders: Diagnostic and coding manual (ICSD)*. Rochester, MN: Author.
- Antrobus, J. (1983). REM and NREM sleep reports: Comparison of word frequencies by cognitive classes. *Psychophysiology*, *20*, 562–568.
- Arkin, A. M., Antrobus, J. A., & Ellman, S. J. (Eds.) (1976). *The mind in sleep. Psychology and psychophysiology*. Hillsdale, NJ: Lawrence Erlbaum.
- Aserinsky, E. & Kleitman, N. (1953). Regularly occurring periods of eye motility and concomitant phenomena during sleep. *Science*, *118*, 273–274.
- Atkinson, R. (1993). Short-term exposure to REST: Enhanced performance on a signal-detection task. In A. F. Barabasz & M. Barabasz (Eds.), *Clinical and experimental restricted environmental stimulation. New Developments and perspectives* (pp. 93–100). New York: Springer.
- Avant, L. L. (1965). Vision in the ganzfeld. *Psychological Bulletin*, *64*(4), 246–258.
- Baars, B. J. (1988). *A cognitive theory of consciousness*. Cambridge: Cambridge University Press.
- Babloyantz, A. (1989). Estimation of correlation dimensions from single and multi-channel recordings – a critical view. In E. Basar & T. H. Bullock (Eds.), *Brain dynamics – progress and perspectives* (pp. 122–130). Berlin: Springer.
- Baldeweg, T. Spence, S., Hirsch, J., & Gruzelier, J. (1998). Gamma-band EEG oscillations in a patient with somatic hallucinations. *The Lancet*, *352*, 620–621.
- Bancaud, J., Brunet-Bourgin, F., Chauvel, P., & Halgren, E. (1994). Anatomical origin of déjà vu and vivid ‘memories’ in human temporal lobe epilepsy. *Brain*, *117*, 71–90.
- Bast Pettersen, R. (1999). Long-term neuropsychological effects in non-saturation construction divers. *Aviation, Space, and Environmental Medicine*, *70*(1), 51–57.

- Behrendt, R.-P. & Young, C. (2003). Hallucinations in schizophrenia, sensory impairment and brain disease: A unifying model. *Behavioural & Brain Sciences*, in press.
- Bem, D. & Honorton, C. (1994). Does psi exist? Replicable evidence for an anomalous process of information transfer. *Psychological Bulletin*, *115*, 4–18.
- Benson, H. (1975). *The relaxation response*. New York: Morrow.
- Ben-Tovim, D. I., & Walker, M. K. (1991). Further evidence for the Stoop test as a quantitative measure of psychopathology in eating disorders. *International Journal of Eating Disorders*, *10*(5), 609–613.
- Berkhoff, M., Donati, F., & Basetti, C. (2000). Postanoxic alpha (theta) coma: A reappraisal of its prognostic significance. *Clinical Neurophysiology*, *111*(2), 297–304.
- Bhargava, R., Mukerji, S., & Sachdeva, U. (2000). Psychological impact of the Antarctic winter on Indian expeditioners. *Environment and Behavior*, *32*(1), 111–127.
- Bien, C. G., Benninger, F. O., Urbach, H., Schramm, J., Kurthen, M., & Elger, C. E. (2000). Localizing value of epileptic visual auras. *Brain*, *123*, 244–253.
- Birbaumer, N. & Kimmel, H.D. (Eds.) (1979). *Biofeedback and self-regulation*. New York: Wiley.
- Birbaumer, N. (1977). Operant enhancement of EEG-theta activity. In J. Beatty & H. Legewie (Eds.), *Biofeedback and behavior* (pp. 135–145). New York: Plenum.
- Birbaumer, N. (1984). Operant control of slow brain potentials: A tool in the investigation of the potential's meaning and its relation to attentional dysfunction. In T. Elbert, B. Rockstroh, W. Lutzenberger, & N. Birbaumer (Eds.), *Self-regulation of the brain and behaviour* (pp. 227–239). Berlin: Springer.
- Birbaumer, N., Elbert, T. Rockstroh, B., & Lutzenberger, W. (1981). Biofeedback of event-related slow potentials of the brain. *International Journal of Psychophysiology*, *16*, 389–415.

- Birbaumer, N., Elbert, T., Canavan, A. G. M., & Rockstroh, B. (1990). Slow potentials of the cerebral cortex and behavior. *Physiological Reviews*, *70*, 1–41.
- Birbaumer, N., Elbert, T., Rockstroh, B., Daum, I., Wolf, P., & Canavan, A. (1991). Clinical-psychological treatment of epileptic seizures: A controlled study. In: A. Ehlers (Ed.), *Perspectives and promises in clinical psychology* (pp. 81–96). New York: Plenum.
- Birbaumer, N., Ghanayim, N., Hinterberger, T., Iversen, I., Kotchoubey, B., Kübler, A., Perelmouter, J., Taub, E., & Flor, H. (1999). A spelling device for the paralysed. *Nature*, *398*, 297–98.
- Blackmore, S. (1996). Near-death experiences. In G. Stein, *The encyclopedia of the paranormal* (pp. 425–441). Amherst, NY: Prometheus.
- Blanke, O., Landis, Th., Spinelli, L., & Seeck, M. (2004). Out-of-body experience and autoscapy of neurological origin. *Brain*, *127*, 243–258.
- Bourguignon, E. (1966). World distribution and patterns of possession states. In R. Prince (Ed.), *Trance and possession states* (pp. 3–34). Montreal: R.M. Burket Memorial Society.
- Bourguignon, E. (1973). *Religion, altered states of consciousness and social change*. Columbus: Ohio State University Press.
- Bowers, K. S. (1992) Imagination and dissociation in hypnotic responding. *International Journal of Clinical and Experimental Hypnosis*, *40*, 253–275.
- Brauchli, P., Michel, C. M., & Zeier, H. (1995). Electrocortical, autonomic, and subjective responses to rhythmic audio-visual stimulation. *International Journal of Psychophysiology*, *19*, 53–66.



- Braud, W. G., Wood, R., & Braud, L. W. (1975). Free-response GESP performance during an experimental hypnagogic state induced by visual and acoustic ganzfeld techniques: A replication and extension. *Journal of the American Society for Psychical Research*, *69*, 105–113.
- Braun, A. R., Balkin, T. J., Wesensten, N. J., Gwadry, F., Carson, R. E., Varga, M., Baldwin, P., Belenky, G. & Herscovitch P. (1998). Dissociated pattern of activity in visual cortices and their projections during human rapid eye movement sleep. *Science*, *279*, 91–95.
- Brennen, T., Matinussen, M., Hansen, B. O., & Hjemdal, O. (1999). Arctic cognition: A study of cognitive performance in summer and winter at 69 degrees N. *Applied Cognitive Psychology*, *13*, 561–580.
- Brinciotti, M., Di Sabato, M. L., Matricardi, M., & Guidetti, V. (2000). Electroclinical features in children and adolescents with epilepsy and/or migraine, and occipital epileptiform EEG abnormalities. *Clinical Electroencephalography*, *31*, 76–82.
- Bristol-Power, M. M., & Spinella, G. (1999). Research in screening and diagnosis in autism: A work in progress. *Journal of autism and developmental disorders*, *29*(6), 435–438.
- Brubakk, A. O. (2000). Man in extreme environments. *Aviation, Space, and Environmental Medicine*, *71*(9,Sect2,Suppl), A126–A130.
- Brugger, P., Regard, M., Landis, T., & Oelz, O. (1999). Hallucinatory experiences in extreme-altitude climbers. *Neuropsychiatry, Neuropsychology, and Behavioral Neurology*, *12*(1), 67–71.
- Cantero, J. L., Atienza, M., Salas, R. M., & Gomez, C. M. (1999). Brain spatial microstates of human spontaneous alpha activity in relaxed wakefulness. *Brain Topography*, *11*, 257–263.

- Cardeña, E., Lynn, S. J., & Krippner, S. (Eds.) (2000). *Varieties of anomalous experience: Examining the scientific evidence*. Washington, DC: American Psychological Association.
- Carmant, L., Carrazana, E., Kramer, U., Helmers, S. L., Holmes, G. L., Black, P. M., & Mikati, M. A. (1996). Pharyngeal dysesthesia as an aura in temporal lobe epilepsy. *Epilepsia*, *37*, 911–913.
- Carr, G. P. (1991). Human experience in space. *Cutis*, *48*(4), 289–290.
- Charles, A., Allmann, F., & Ragot, P. (2001). Diving and cognitive performance: The selective impairment of control processes, In F. Columbus (Ed.), *Advances in psychology research*, Vol. 2. (pp. 185–192). Huntington, NY: Nova Science.
- Childs, N. L., & Merger, W. N. (1996). Brief report: Late improvement in consciousness after posttraumatic vegetative state. *New England Journal of Medicine*, *334*, 24–25.
- Chowdhury, B. (2000). *The last dive: A father and son's fatal descent into the ocean's depths*. New York: HarperCollins.
- Chritchley, H. D., Corfield, D. R., Chandler, M. P., Mathias, C. J., Dolan, R. J. (2000). Cerebral correlates of autonomic cardiovascular arousal: A functional neuroimaging investigation in humans. *Journal of Physiology*, *523*, 259–270.
- Chritchley, H. D., Melmed, R. N., Featherstone, E., Mathias, C. J., & Dolan, R. J. (2001). Brain activity during biofeedback relaxation: A functional neuroimaging investigation. *Brain*, *124*, 1003–1012.
- Cohadon, F. & Richer, E. (1993). Stimulation cérébrale profonde chez des patients en état végétatif post-traumatique: 25 observations. *Neurochirurgie*, *39*(5), 281–292.
- Cohen, A. S., Rosen, R.C., & Goldstein, L. (1985). EEG hemispheric asymmetry during sexual arousal: psychophysiological patterns in responsive, unresponsive, and dysfunctional men. *Journal of Abnormal Psychology*, *94*, 580–590.

- Cohen, H. D., Rosen, R.C., & Goldstein, L. (1976). Electroencephalographic laterality changes during human sexual orgasm. *Archives of Sexual Behavior*, 5, 189–99.
- Crawford, H. J. & Gruzelier, J. H. (1992). A midstream view of the neuropsychophysiology of hypnosis: Recent research and future directions. In E. Fromm & M. R. Nash (Eds.), *Contemporary hypnosis research* (pp. 227–266). New York: Guilford Press.
- Crawford, H. J., Knebel, T., & Vendemia, M. C. (1998). The nature of hypnotic analgesia: Neurophysiological foundation and evidence. *Contemporary Hypnosis*, 15, 22–33.
- Crawford, J. H. (1994) Brain dynamics and hypnosis: Attentional and disattentional processes. *International Journal of Clinical and Experimental Hypnosis*, 42, 204–232.
- Croft, R. J., Williams, J. D., Haenschel, C., & Gruzelier, J. H. (2002). Pain perception, 40 Hz oscillations and hypnotic analgesia. *International Journal of Psychophysiology*, 46, 101–108.
- Cunningham, S., Scerbo, M. W., & Freeman, F. G. (2000). The electrocortical correlates of daydreaming during vigilance tasks. *Journal of Mental Imagery*, 24, 61–72.
- Curcio, G., Casagrande, M., & Bertini, M. (2001). Sleepiness: evaluating and quantifying methods. *International Journal of Psychophysiology*, 41, 251–263.
- Davies, D. R. & Tune, G. S. (1970). *Human Vigilance Performance*. London: Staples Press.
- Davis, H., Davis, P. A., Loomis, A. L., Harvey, E. N., & Hobart, G. (1937). Changes in human brain potentials during the onset of sleep. *Science*, 86, 448–450.
- De Pascalis, V. (1999) Psychophysiological correlates of hypnosis and hypnotic susceptibility. *International Journal of Clinical and Experimental Hypnosis*, 47, 117–143.
- Dehaene, S. (Ed.) (2001). *The cognitive neuroscience of consciousness*. Cambridge: MIT Press.

- Dehaene, S. & Naccache, L. (2001): Towards a cognitive neuroscience of consciousness: basic evidence and a workspace framework. In: S. Dehaene (ed.), *The cognitive neuroscience of consciousness* (pp. 1–37). Cambridge: MIT Press.
- Delvenne, V., Goldman, S., Biver, F., De Maertelaer, V., Wikler, D., Damhaut, P., & Lotstra, F. (1997). Brain hypometabolism of glucose in low-weight depressed patients and in anorectic patients: a consequence of starvation? *Journal of Affective Disorders*, *41*(1), 69–77.
- Delvenne, V., Goldman, S., De Maertelaer, V., Simon, Y., Luxen, A., & Lotstra, F. (1996). Brain hypometabolism of glucose in anorexia nervosa: normalization after weight gain. *Biological Psychiatry*, *40*(8), 761–768.
- Dittrich, A., von Arx, S., & Staub, S. (1985). International study on altered states of consciousness (ISASC). Summary of the results. *German Journal of Psychology*, *9*, 319–339.
- Dua, S. & MacLean, P. D. (1964). Localisation for penile erection in medial frontal lobe. *American Journal of Physiology*, *207*, 1425–1434.
- Dudley Rowley, M. (1997). Deviance among expeditioners: Defining the off-nominal act through space and polar field analogs. *Human Performance in Extreme Environments*, *2*(1), 119–127.
- Dvorak, I. (1990). Takens versus multichannel reconstruction in EEG correlation exponent estimations. *Physics Letters Series A*, *132*, 101–106.
- Easterlin, B. L. & Cardena, E. (1998). Cognitive and emotional differences between short- and long-term Vipassana meditators. *Imagination, Cognition and Personality*, *18*(1), 69–81.

- Egner, T. & Gruzelier, J. H. (2001). Learned self-regulation of EEG frequency components affects attention and event-related brain potentials in humans. *Neuroreport*, *12* (18), 4155–4159.
- Egner, T. & Gruzelier, J. H. (2003). Ecological validity of neurofeedback: Modulation of slow wave EEG enhances musical performance. *Neuroreport*, *14*(9), 1221–1224.
- Egner, T. & Gruzelier, J. H. (2004). EEG Biofeedback of low beta band components: Frequency-specific effects on variables of attention and event-related brain potentials. *Clinical Neurophysiology*, *115* (1), 131–139.
- Farthing, G. W. (1992). *The psychology of consciousness*. Englewood Cliffs, NJ: Prentice Hall.
- Farvolden, P. & Woody, E.Z. (2004). Hypnosis, memory, and frontal executive functioning. *International Journal of Clinical and Experimental Hypnosis*, *52*, 3–26.
- Feinberg, I. & Guazzelli, M. (1999). Schizophrenia – a disorder of the corollary discharge systems that integrate the motor systems of thought with the sensory systems of consciousness. *British Journal of Psychiatry*, *174*, 196–204.
- Feinberg, I. (1978). Efference copy and corollary discharge: implications for thinking and its disorders. *Schizophrenia Bulletin*, *4*, 636–640.
- Feinberg, I. (1982). Schizophrenia: caused by a fault in programmed synaptic elimination during adolescence? *Journal of Psychiatric Research*, *17*, 319–334.
- Fenwick, P. (1987). Meditation and the EEG. In M. A. West (Ed.), *The psychology of meditation* (pp. 104–117). Oxford: Oxford University Press.
- Fischer, C., Morlet, D., Bouchet, P., Luaute, J., Jourdan, C., & Salord, F. (1999). Mismatch negativity and late auditory evoked potentials in comatose patients. *Clinical Neurophysiology*, *110*(9), 1601–1610.

- Fletcher, P. (1998). The missing link: a failure of fronto-hippocampal integration in schizophrenia. *Nature Neuroscience*, 1(4), 266–267.
- Flor-Henry, P. (1980). Cerebral aspects of the orgasmic response: normal and deviational. In R. Forleo & W. Pasini (Eds.), *Medical sexology*. Amsterdam: Elsevier.
- Forgays, D. G. & Forgays, D. K. (1992). Creativity enhancement through flotation isolation. *Journal of Environmental Psychology*, 12(4), 329–335.
- Foulkes, D. & Pope, R. (1973). Primary visual experiences and secondary cognitive elaboration in stage REM: A modest conformation and an extension. *Perceptual and Motor Skills*, 37, 107–118.
- Foulkes, D. & Schmidt, M. (1983). Temporal sequence and unit composition in dream reports from different stages of sleep. *Sleep*, 6, 265–280.
- Foulkes, D. & Vogel, G. (1965). Mental activity at sleep onset. *Journal of Abnormal Psychology*, 70, 231–243.
- Foulkes, D. (1996). Dream research: 1953–1993. *Sleep*, 19, 609–624.
- Fowler, B., Comfort, D., & Bock, O. (2000). A review of cognitive and perceptual-motor performance in space. *Aviation Space and Environmental Medicine*, 71(9), A66–A68.
- Freeman, W. (1973). Sexual behavior and fertility after frontal lobotomy. *Biological Psychiatry*, 6, 97–104.
- Freud, S. (1900). *Die Traumdeutung*. Leipzig: Deuticke.
- Friederich, M., Trippe, R. H., Özcan, M., Weiss, T., Hecht, H., & Miltner, W. H. R. (2001). Laser evoked potentials to noxious stimulation during hypnotic analgesia and distraction of attention suggest different brain mechanisms of pain control. *Psychophysiology*, 38, 768–776.
- Friederici, A. D. & Levelt, W. J. (1990). Spatial reference in weightlessness: Perceptual factors and mental representations. *Perception and Psychophysics*, 47(3), 253–266.

- Gardner, R., Grossman, W. I., Roffwarg, H. P., & Weiner, H. (1975). The relationship of small limb movements during REM sleep to dreamed limb action. *Psychosomatic Medicine*, 37, 147–159.
- Gardner, W. N. (1996). The pathophysiology of hyperventilation disorders. *Chest*, 2, 516–534.
- Gazzaniga, M. (Ed.) (2000). *The new cognitive neurosciences*. Cambridge: MIT Press.
- Gentleman, D. (1999). Improving outcome after traumatic brain injury – progress and challenges. *British Medical Bulletin*, 55(4), 910–926.
- Gerne, M. & Strauch, I. (1985). Psychophysiological indicators of affect patterns and conversational signals during sleep. In W.P. Koella, E. Rütger, & H. Schulz (Eds.), *Sleep'84* (pp. 367–369). Stuttgart: Gustav Fischer.
- Giambra, L. M. (1999–2000). The temporal setting, emotions, and imagery of daydreams: Age changes and age differences from late adolescent to the old. *Imagination, Cognition and Personality*, 19, 367–413.
- Glide, S. (1994). Maintaining sensory balance. *Nursing Times*, 90(17), 33–34.
- Gloor, P. (1990). Experiential phenomena of temporal lobe epilepsy. Facts and hypotheses. *Brain*, 113, 1673–1694.
- Gorman, D. G., & Cummings, J. L. (1992). Hypersexuality following septal injury. *Archives of Neurology*, 49, 308–310.
- Gott, P. S., Rabinovicz, A. L., & DiGiorgio, C. M. (1991). P300 auditory event-related potentials in nontraumatic coma: Association with Glasgow Coma Score and awakening. *Archives of Neurology*, 48(12), 1267–1270.
- Graber, B., Rohrbaugh, J. W., Newlin, D. B., Varner, J. L., & Ellingson, R. J. (1985). EEG during masturbation and ejaculation. *Archives of Sexual Behavior*, 14, 491–503.

- Graybiel, A.M. (1997). The basal ganglia and cognitive pattern generators. *Schizophrenia Bulletin*, 23, 459–469.
- Greenwood, M. M. & Benson, H. (1977). The efficacy of progressive relaxation in systematic desensitization and a proposal for an alternative competitive response – The relaxation response. *Behavioural Research Therapy*, 15, 337 – 343.
- Greyson, B. (2000). Near-death experiences. In E. Cardeña, S. J. Lynn, & S. Krippner (Eds.), *Varieties of anomalous experience: Examining the scientific evidence* (pp. 315–351). Washington, DC: American Psychological Association.
- Grof, S. (1976). *Realms of the human unconscious: Observation from LSD research*. New York: Viking.
- Grossman, P., Janssen, K. H. L., & Vaitl, D. (Eds.) (1986). *Cardiorespiratory and cardiosomatic psychophysiology*. NATO ASI Series. New York: Plenum.
- Grunwald, M., Ettrich, C., Assmann, B., Dahne, A., Krause, W., Busse, F., & Gertz, H. J. (2001). Deficits in haptic perception and right parietal theta power changes in patients with anorexia nervosa before and after weight gain. *International Journal of Eating Disorders*, 29(4), 417–428.
- Gruzelier, J. H. (1979). Synthesis and critical review of the evidence for hemisphere asymmetries of function in psychopathology. In J. H. Gruzelier & P. Flor-Henry (Eds.), *Hemispheric asymmetries of function in psychopathology* (pp. 647–672). Amsterdam: Elsevier.
- Gruzelier, J. H. (1998). A working model of the neurophysiology of hypnosis: A review of the evidence. *Contemporary Hypnosis*, 15, 3–21.
- Gruzelier, J. H. (1999a). Functional neuro-psychophysiological asymmetry in schizophrenia: A review and reorientation. *Schizophrenia Bulletin*, 25(1), 91–120.



- Gruzelier, J. H. (1999b). A review of the implications of early sensory processing and subcortical involvement for cognitive dysfunction in schizophrenia. In C. Tamminga (Ed.), *Review of Psychiatry, 25, Section Schizophrenia in the molecular age* (pp. 29–76). New York: American Psychiatric Association,.
- Gruzelier, J. H. (2000). Redefining hypnosis: Theory, methods and integration. *Contemporary Hypnosis, 17*, 51–70.
- Gruzelier, J. H. (2002). A Janusian perspective on the nature, development and structure of schizophrenia and schizotypy. *Schizophrenia Research, 54*(1–2), 95–103.
- Gruzelier, J. H. & Warren, K. (1993). Neuropsychological evidence of reductions on left frontal tests with hypnosis. *Psychological Medicine, 23*, 93–101.
- Gruzelier, J. H., Hardman, E., Wild, J., & Zaman, R. (1999). Learned control of slow potential interhemispheric asymmetry in schizophrenia. *International Journal of Psychophysiology, 34*, 341–348.
- Guilleminault, C., Billard, M., Montplaisir, J., & Dement, W. C. (1972). Altered states of consciousness in disorders of daytime sleepiness. *Journal of Neurological Sciences, 26*, 377–393.
- Hackett, P. H., & Roach, R. C. (2001). High-Altitude Illness. *New England Journal of Medicine, 345*(2), 107–114.
- Haggarty, J., Cernovsky, Z., Kermeen, P., & Merskey, H. (2000). Psychiatric disorders in an Arctic community. *Canadian Journal of Psychiatry, 45*(4), 357–362.
- Halm, M. A. & Alpen, M. A. (1993). The impact of technology on patients and families. *Nursing clinics of North America, 28*(2), 443–457.
- Hamad, N. M., Fine, T. H., & Turner, J. W. (1996). Effects of restricted environmental stimulation therapy (REST) on plasma levels of epinephrine and norepinephrine. *Biofeedback and Self-Regulation, 21*(4), 359–360.

- Harsh, J. R. (1994). Event-related potential changes during the wake-to-sleep transition. In R. D. Ogilvie & J. R. Harsh (Eds.), *Sleep onset. Normal and abnormal processes* (pp. 309–326). Washington DC: American Psychological Association.
- Head, H. (1923). The conception of nervous and mental energy. II. Vigilance: A physiological state of the nervous system. *British Journal of Psychology*, *14*, 126–147.
- Heath, R.G. (1972). Pleasure and brain activity in men. *The Journal of Nervous and Mental Disease*, *154*, 3–18.
- Hebb, D. O. (1949). *The Organization of Behavior: A neuropsychological theory*. New York: Wiley.
- Hebert, R. & Lehmann, D. (1977). Theta bursts: An EEG pattern in normal subjects practising the transcendental meditation technique. *Electroencephalography and Clinical Neurophysiology*, *42*(3), 397–405.
- Herrmann, W. M., Kubicki, S. K., & Röhmel, J. (1988). Vigilance classification system: Development, sample values, and applications in nootropic drug research. *Zeitschrift für Gerontopsychologie und -psychiatrie*, *1*, 1–33.
- Hilgard, E. R. & Hilgard, J. R. (1983). *Hypnosis in the relief of pain*. Kaufmann, Los Altos.
- Hobson, J. A. (1999). The new neuropsychology of sleep: Implications for psychoanalysis. *Neuro-Psychoanalysis*, *1*, 157–183.
- Hobson, J. A., Pace-Schott, E. F., & Stickgold, R. (2000). Dreaming and the brain: Toward a cognitive neuroscience of conscious states. *Behavioral and Brain Sciences*, *23*(6), 793–842.
- Honorton, C. & Harper, S. (1974). Psi-mediated imagery and ideation in an experimental procedure for regulating perceptual input. *Journal of the American Society for Psychical Research*, *68*, 156–168.

- Honorton, C., Berger, R. E., Varvoglis, M. P., Quant, M., Derr, P., Schechter, E. I., & Ferrari, D. C. (1990). Psi communication in the ganzfeld. Experiments with an automated testing system and a comparison with a meta-analysis of earlier studies. *Journal of Parapsychology, 54*, 99–139.
- Hori, T., Hayashi, M., & Morikawa, T. (1994). Topographical EEG changes and the hypnagogic experience. In R. D. Ogilvie & J. R. Harsh (Eds.), *Sleep onset. Normal and abnormal processes* (pp. 237–253). Washington DC: American Psychological Association.
- Huon, G. F. & Brown, L. B. (1996). Task dependence in color-naming latency among dieters. *International Journal of Eating Disorders, 19*(4), 405–410.
- Hyde, T. M., Ziegler, J. C., & Weinberger, D.R. (1992). Psychiatric disturbances in metachromatic leukodystrophy. Insights into the neurobiology of psychosis. *Archives of Neurology and Psychiatry, 49*, 401–406.
- Isotani, T., Lehmann, D., Pascual-Marqui, R. D., Kochi, K., Wackermann, J., Saito, N., Yagy, T., Kinoshita, T., & Sasada, K. (2001a). EEG source localization and global dimensional complexity in high- and low-hypnotizable subjects: A pilot study. *Neuropsychobiology, 44*, 192–198.
- Isotani, T., Tanaka, H., Lehmann, D., Pascual Marqui, R. D., Kochi, K., Saito, N., Yagy, T., Kinoshita, T., & Sasada, K. (2001b). Source localization of EEG activity during hypnotically induced anxiety and relaxation. *International Journal of Psychophysiology, 41*(2), 143–153.
- Jacobs, G. D., Benson, H., & Friedman, R. (1996). Topographic EEG mapping of the relaxation response. *Biofeedback and Self-Regulation, 21*, 121–129.
- Jacobs, L., Feldman, B., & Bender, M. B. (1972). Are the eye movements of dreaming sleep related to the visual images of dreams? *Psychophysiology, 9*, 393–401.

- James, W. (1890). *The principles of psychology (chapter IX)*. New York: Holt.
- Jansen, K. L. R. (1997). The ketamine model of the near-death experience: A central role for the N-methyl-D-aspartate receptor. *Journal of Near-Death Studies, 16*(1), 5–26.
- Jung, T.-P., Makeig, S., Stensmo, M., & Sejnowski, T. (1997). Estimating alertness from the EEG power spectrum. *IEEE Transactions on Biomedical Engineering, 44*, 60–69.
- Kahn, P. M. & Leon, G. R. (1994). Group climate and individual functioning in an all women's Antarctic expedition team. *Environment and Behavior, 26*, 669–697.
- Kaiser, J. & Gruzelier, J. H. (1999). Timing of puberty and syndromes of schizotypy: A replication. *International Journal of Psychophysiology, 34*, 237–248.
- Kaiser, J., Barker, R., Haenschel, C., Baldeweg, T. & Gruzelier, J. (1997). Hypnosis and event-related potential correlates of error processing in a stroop-type paradigm: A test of the frontal hypothesis. *International Journal of Psychophysiology, 27*, 215–222.
- Kallio, S., Revonsuo, A., Hamalainen, H., & Gruzelier, J. H. (2000). Anterior brain functions and hypnosis; A test of the frontal hypothesis. *International Journal of Clinical and Experimental Hypnosis, 49*, 95–108.
- Kamiya, J. (1969). Operant control of the EEG alpha rhythm and some of its effects on consciousness. In C. T. Tart (Ed.), *Altered states of consciousness* (pp. 489–501). New York: Wiley.
- Kane, N. M., Butler, S. R., & Simpson, T. (2000). Coma outcome prediction using event-related potentials: P3 and mismatch negativity. *Audiology and Neuro-Otology, 5*, 186–191.
- Kane, N. M., Curry, S. H., Rowlands, C. A., Minara, A. R., Lewis, T., Moss, T., Cummins, B. H., & Butler, S. R. (1996). Event-related potentials - neurophysiological tools for predicting emergence and early outcome from traumatic coma. *Intensive Care in Medicine, 22*, 39–46.

- Kaplan, P. W., Genoud, D., Ho, T. W., & Jallon, P. (2000). Clinical correlates and prognosis in early spindle coma. *Clinical Neurophysiology*, *111*, 584–590.
- Kirsch, I. (2000). The response set theory of hypnosis. *American Journal of Clinical Hypnosis*, *42*, 274–301.
- Klinger, E. (1978). Modes of normal conscious flow. In K. S. Pope & J. L. Singer (Eds.), *The stream of consciousness* (pp. 91–116). London: Plenum Press.
- Koenig, T., Lehmann, D., Merlo, M., Kochi, K., Hell, D., & Koukkou, M. (1999). A deviant EEG brain microstate in acute, neuroleptic-naïve schizophrenics at rest. *European Archives of Psychiatry and Clinical Neuroscience*, *249*, 205–211.
- Koenig, T., Prichep, L. S., Lehmann, D., Valdes-Sosa, P., Braeker, E., Kleinlogel, H., Isenhardt, R., & John, E. R. (2002). Millisecond by millisecond, year by year: Normative EEG microstates and developmental stages. *NeuroImage*, *16*, 41–48.
- Kotchoubey B., Schneider D., Strehl U., Uhlmann C., Blankenhorn V., Fröscher W., & Birbaumer, N. (1996). Self-regulation of slow cortical potentials in epilepsy: A retrieval with analysis of influencing factors. *Epilepsy Research*, *25*, 269–276
- Kotchoubey, B., Lang, S., Baales, R., Herb, E., Maurer, P., Mezger, G., Schmalohr, D., Bostanov, V., & Birbaumer, N. (2001). Brain potentials in human patients with severe diffuse brain damage. *Neuroscience Letters*, *301*, 37–40.
- Kotchoubey, B., Strehl, U., Holzapfel, S., Blankenhorn, V., Fröscher, W., & Birbaumer, N. (1999). Negative potential shifts and the prediction of the outcome of neurofeedback therapy in epilepsy. *Clinical Neurophysiology*, *110*, 683–686.
- Kotchoubey, B., Strehl, U., Uhlmann, C., Holzapfel, S., König, M., Fröscher, W., Blankenhorn, V. & Birbaumer, N. (2001). Modification of slow cortical potentials in patients with refractory epilepsy: A controlled outcome study. *Epilepsia*, *42*, 406–416.

- Koukkou, M. & Lehmann, D. (1983). Dreaming: The functional state-shift hypothesis. A neurophysiological model. *British Journal of Psychiatry*, *142*, 221–231.
- Koukkou, M., Lehmann, D., Strik, W. K., & Merlo, M. C. (1994). Maps of microstates of spontaneous EEG in never-treated acute schizophrenia. *Brain Topography*, *6*, 251–252.
- Koukkou, M., Lehmann, D., Wackermann, J., Dvorak, I., & Henggeler, B. (1993). Dimensional complexity of EEG brain mechanisms in untreated schizophrenia. *Biological Psychiatry*, *33*, 397–407.
- Kübler, A., Kotchoubey, B., Kaiser, J., Wolpaw, J. R., & Birbaumer, N. (2001). Brain-Computer-Communication: Unlocking the locked in. *Psychological Bulletin*, *127*(3), 358–375.
- Kuhlman, W. N. (1978). EEG feedback training: Enhancement of somato-sensory cortical activity. *Electroencephalography and Clinical Neurophysiology*, *44*, 290–294.
- Kuhlo, W. & Lehmann, D. (1964). Das Einschlafen und seine neurophysiologische Korrelate. *Archiv für Psychiatrie und Zeitschrift für die gesamte Neurologie*, *205*, 687–216.
- Kumar, V. K. & Pekala, R. J. (1988). Hypnotizability, absorption, and individual differences in phenomenological experience. *International Journal of Clinical and Experimental Hypnosis*, *36*(2), 80–88.
- LaBerge, S. (2000). Lucid dreaming: Evidence and methodology. *Behavioral and Brain Sciences* *23*(6), 962–963.
- Ladd, G. T. (1892). Contribution to the psychology of visual dreams. *Mind*, *1*, 299–304.
- Lautenbacher, S., Pauls, A. M., Strian, F., Pirke, K. M., & Krieg, J. C. (1991). Pain sensitivity in anorexia nervosa and bulimia nervosa. *Biological Psychiatry*, *29*(11), 1073–1078.

- Lavie, P. (1979). Ultradian rhythm in alertness. A pupillometric study. *Biological Psychology*, 9, 49–62.
- Lawrie, S. M., Buechel, C., Whalley, H. C., Frith, C. D., Friston, K. J., & Johnstone, E. C. (2002). Reduced frontotemporal functional connectivity in schizophrenia associated with auditory hallucinations. *Biological Psychiatry*, 51(12), 1008–1011.
- Lazar, S. W., Bush, G., Gollub, R. L., Fricchione, G. L., Khalsa, G., & Benson, H. (2000). Functional brain mapping of the relaxation response and meditation. *NeuroReport*, 11(7), 1581–1585.
- Leaning, F. E. (1925). An introductory study of hypnagogic phenomena. *Proceedings of the Society for Psychological Research*, 35, 289–409.
- Lehmann, D., Faber, P. L., Achermann, P., Jeanmonod, D., Gianotti, L. R. R., & Pizzagalli, D. (2001). Brain sources of EEG gamma frequency during volitionally meditation-induced, altered states of consciousness, and experience of the self. *Psychiatry Research: Neuroimaging*, 108, 111–121.
- Lehmann, D., Faber, P.L., Galderisi, S., Herrmann, W. M., Kinoshita, T., Koukkou, M., Mucci, A., Pascual-Marqui, R.D., Saito, N., Wackermann, J., Winterer, G. and Koenig, T. (in press). EEG microstate duration and syntax in acute, medication-naïve, first-episode schizophrenia: a multi-center study. *Psychiatry Research: Neuroimaging*, in press.
- Lehmann, D., Faber, P., Isotani, T., & Wohlgemuth, P. (2001). Source locations of EEG frequency bands during hypnotic arm levitation: A pilot study. *Contemporary Hypnosis*, 18, 120–127. Erratum in: *Contemporary Hypnosis*, 18: 220 (2001).
- Lehmann, D., Grass, P., & Meier, B. (1995). Spontaneous conscious covert cognition states and brain electric spectral states in canonical correlations. *International Journal of Psychophysiology* 19, 41–52.

- Lehmann, D., Ozaki, H., & Pal, I. (1987). EEG alpha map series: Brain micro-states by space-oriented adaptive segmentation. *Electroencephalography and Clinical Neurophysiology*, 67, 271–288.
- Lehmann, D., Strik, W. K., Henggeler, B., Koenig, T., & Koukkou, M. (1998). Brain electric microstates and momentary conscious mind states as building blocks of spontaneous thinking: I. Visual imagery and abstract thoughts. *International Journal of Psychophysiology*, 29, 1–11.
- Lempert, T., Bauer, M. & Schmidt, D. (1994). Syncope: A videometric analysis of 56 episodes of transient cerebral hypoxia. *Annals of Neurology*, 36(2), 233–237.
- Leroy, E. B. (1933). *Les visions du Demi-Sommeil*. Paris: Alcan.
- Lichstein, K. L. (1988). *Clinical relaxation strategies*. New York: John Wiley & Sons.
- Lilly, J. C. (1956). Mental effects of reduction of ordinary levels of physical stimuli on intact, healthy persons. In A. P. Association (Ed.), *Psychiatric Research Reports*, 5, 1–9.
- Lilly, J. C. (1977). *The deep self*. New York: Simon & Schuster.
- Lindsley D. B. (1960). Attention, consciousness, sleep and wakefulness. In J. Field, H. W. Magoun & V. E. Hall (Eds.), *Handbook of physiology* (Sect. 1, Vol. 3, pp. 1553–1593). Washington DC: American Physiological Society.
- Linschoten, J. (1955). Über das Einschlafen. *Psychologische Beiträge*, 2, 70–97, 266–298.
- Llinas, R. R. & Pare, D. (1991) Commentary on dreaming and wakefulness. *Neuroscience*, 44(3), 521–535
- Llinas, R. R. (2001). *I of the vortex*. Cambridge: MIT Press.
- Llinas, R., Ribary, U., Joliot, M., & Wang, X. J. (1994). Content and context in temporal thalamocortical binding. In: G. Buzaki, R. Llinas, W. Singer, A. Berthoz, & Y. Christen (Eds.), *Temporal coding in the brain* (pp. 251–271). Berlin: Springer.



- Logothetis, N. K., Pauls, J., Augath, M., Trinath, T., & Oeltermann, A. (2001). A neurophysiological investigation of the basis of the fMRI signal. *Nature*, *412*, 150–157.
- Lowenstein, O. & Loewenfeld, I. E. (1964). The sleep—waking cycle and pupillary activity. *Annals of the New York Academy of Sciences*, *117*, 142–156.
- Ludwig, A. M. & Stark, L. H. (1973). Schizophrenia, sensory deprivation, and sensory overload. *Journal of Nervous and Mental Disease*, *157*(3), 210–216.
- Ludwig, A. M. (1966). Altered states of consciousness. *Archives of General Psychiatry*, *15*, 225–234.
- Ludwig, A. M. (1972). „Psychedelic” effects produced by sensory overload. *American Journal of Psychiatry*, *128*(10), 1294–1297.
- Maddox, R. W. & Long, M. A. (1999). Eating disorders: Current concepts. *Journal of the American Pharmacological Association Washington*, *39*(3), 378–387.
- Maharishi Mahesh Yogi (1966). *The science of being and the art of living*. London: International SRM Publ.
- Makeig, S. & Inlow, M. (1993). Lapses in alertness: Coherence of fluctuations in performance and EEG spectrum. *Electroencephalography and Clinical Neurophysiology*, *86*, 23–35.
- Mandell, A. J. (1980). Toward a psychobiology of transcendence: God in the brain. In J. M. Davidson & R. J. Davidson(Eds.), *The psychobiology of consciousness* (pp. 379–464). New York: Plenum.
- Manzey, D. & Lorenz, B. (1999). Human performance during spaceflight. *Human Performance in Extreme Environments*, *4*(1), 8–13.
- Massion, J., Fabre, J. C., Mouchnino, L., & Obadia, A. (1995). Body orientation and regulation of the center of gravity during movement under water. *Journal of Vestibular Research: Equilibrium and Orientation*, *5*(3), 211–221.

- Matejcek, M. (1982). Vigilance and the EEG: Psychological, physiological and pharmacological aspects. In W. M. Hermann (Ed.), *EEG in drug research* (pp. 405–508). Stuttgart: Gustav Fischer.
- Matousek, M. & Petersén, I. (1983). A method for assessment of alertness fluctuations from EEG spectra. *Electroencephalography and Clinical Neurophysiology*, *55*, 108–113.
- Maurer, R. L. S., Kumar, V. K., Woodside, L., & Pekala, R. J. (1997). Phenomenological experience in response to monotonous drumming and hypnotizability. *American Journal of Clinical Hypnosis*, *40*(2), 130–145.
- Maury, A. (1848). Des hallucinations hypnagogiques (ou des erreurs des sens dans l'état intermédiaire entre la veille et le sommeil). *Annales Médico-Psychologiques du Système Nerveux*, *11*, 26–40.
- Mavromatis, A. (1987). *Hypnagogia. The unique state of consciousness between wakefulness and sleep*. London: Routledge & Kegan Paul.
- Maxfield, M. C. (1990). *Effects of rhythmic drumming on EEG and subjective experiences (PhD dissertation)*. Menlo Park, CA: Institute of Transpersonal Psychology.
- McGuire, B. E., Basten, C., Ryan, C., & Gallagher, J. (2000). Intensive care unit syndrome: A dangerous misnomer. *Archives of Internal Medicine*, *160*, 906–909.
- Meduna, L. J. (1950). The effect of carbon dioxide upon the functions of the brain. In: L. J. Meduna (Ed.). *Carbon dioxide therapy* (pp. 23–40). Springfield, IL: Charles C. Thomas.
- Merrin, E. L., Meek, P., Floyd, T. C., & Callaway, E. 3rd. (1990). Topographic segmentation of waking EEG in medication-free schizophrenic patients. *International Journal of Psychophysiology*, *9*, 231–236.
- Messner, R. (2001). *Die Freiheit, aufzubrechen, wohin ich will. Ein Bergsteigerleben*. München: Piper

- Mesulam, M. M. (Ed.) (2000). *Principles of behavioral and cognitive neurology*. Oxford: Oxford University Press.
- Miller, M. E. & Bowers, K. S. (1993). Hypnotic analgesia: Dissociated experience or dissociated control? *Journal of Abnormal Psychology, 102*, 29–38.
- Monroe, L. J., Rechtschaffen, A., Foulkes, D., & Jensen, J. (1965). Discriminability of REM and NREM reports. *Journal of Personality and Social Psychology, 2*, 456–460.
- Morris, T. L. & Mitler, J. C. (1996). Electrooculographic and performance indices and its possible application in psychopharmacology. *Pharmakopsychiatrie und Neuropsychopharmakologie, 12*, 148–154.
- Morse, M. L., Venecia, D., & Milstein, J. (1989). Near-death experiences: A neurophysiologic explanatory model. *Journal of Near-Death Studies, 8*(1), 45–53.
- Mosovich, A., & Tallaferrero, A. (1954). Studies on EEG and sex function orgasm. *Diseases of the Nervous System, 15*, 218–220.
- Müller, J. (1826). *Ueber die phantastischen Gesichterserscheinungen. Eine physiologische Untersuchung*. Coblenz: Jacob Hölscher. [Reprint: München: W. Fritsch, 1967.]
- Murphy, M. & Donovan, S. (1997). *The physical and psychological effects of meditation. A review of contemporary research with a comprehensive bibliography 1931–1996*. Sausalito, CA: Institute of Noetic Sciences.
- Murri, L., Arena, R., Siciliano, G., Mazzotta, R., & Muratorio, A. (1984). Dream recall in patients with focal cerebral lesions. *Archives of Neurology, 41*, 183–185.
- Mutschler, V., Chaumeil, C. G., Marcoux, L., Wioland, N., Tempe, J. D., & Kurtz, D. (1996). Etude du P300 auditif chez des sujets en coma post-anoxique. Données préliminaires. *Neurophysiologie Clinique, 26*(3), 158–163.
- Myers, F. W. H. (1904). *Human personality and its survival of bodily death. (Vol I)*. New York: Longmans, Green and Co.

- Naifeh, K. H., Kamiya, J., & Sweet, D.M. (1982). Biofeedback of alveolar carbon dioxide tension and levels of arousal. *Biofeedback and Self-Regulation*, 7, 283–299.
- Narita, T., Morozumi, S., & Yagi, T. (1987). Psychophysiological analysis during autogenic training. *Advances in Biological Psychiatry*, 16, 72–89.
- Nasrallah, H. A. (1985). The unintegrated right cerebral hemispheric consciousness as alien intruder: A possible mechanism for Schneiderian delusions in schizophrenia. *Comprehensive Psychiatry*, 26(3), 273–282.
- Neher, A. (1961). Auditory Driving Observed with Scalp Electrodes in Normal Subjects. *Electroencephalography and Clinical Neurophysiology*, 13, 449–451.
- Neher, A. (1962). A physiological explanation of unusual behavior in ceremonies involving drums. *Human Biology*, 34, 151–160.
- Newberg, A. B. & d’Aquili, E. G. (2000). The neuropsychology of religious and spiritual experience. *Journal of Consciousness Studies*, 7(11), 251–266.
- Newell, A. (1992). Precis of unified theories of cognition. *Behavioral and Brain Sciences*, 15, 425–492.
- Niedermeyer, E. & Lopes da Silva, F. (1999). *Electroencephalography* (4th ed.). Baltimore: Williams & Wilkins.
- Niedermeyer, E. (1999). A concept of consciousness. *Italian Journal of Neurological Science*, 20, 7–15.
- Ohayon, M. M., Priest, R.G., Caulet, M., & Guilleminault, C. (1996). Hypnagogic and hypnopompic hallucinations: Pathological phenomena? *British Journal of Psychiatry*, 169, 459–465.
- Oke, A .F. & Adams,R. N. (1987) Elevated thalamic dopamine: Possible link to sensory dysfunctions in schizophrenia. *Schizophrenia Bulletin*, 13(4), 589–603.
- Oswald, I. (1962). *Sleeping and waking. Physiology and Psychology*. Amsterdam: Elsevier.

- Ott, U., Sammer, G., & Vaitl, D. (2002). Baroreflex responsiveness correlates with the trait of absorption. *International Journal of Psychophysiology*, *45*(1–2), 16–17.
- Palinkas, L. A. (1992). Going to extremes: The cultural context of stress, illness and coping in Antarctica. *Social Science & Medicine*, *35*(5), 651–664.
- Palinkas, L. A., Gunderson, E. K. E., Johnson, J. C., & Holland, A. W. (2000). Behavior and performance on long-duration spaceflights: Evidence from analogue environments. *Aviation, Space and Environmental Medicine*, *71* (Suppl 1), A29–A36.
- Palus, M., Dvorak, I., & David, I. (1990). Remarks on spatial and temporal dynamics of EEG. In I. Dvorak & A.V. Holden (Eds.), *Mathematical approaches to brain functioning diagnostics* (pp. 369–385). Manchester: Manchester University Press.
- Panayiotopoulos, C. P. (2001). Treatment of typical absence seizures and related epileptic syndromes. *Paediatric Drugs*, *3*, 379–403.
- Parker, A. (1975). Some findings relevant to the change in state hypothesis. In J. D. Morris, W. G. Roll, & R. L. Morris (Eds.), *Research in parapsychology* (pp. 40–42). Metuchen, NJ: Scarecrow.
- Parrott, A. C. (2001). Human psychopharmacology of Ecstasy (MDMA): a review of 15 years of empirical research. *Human Psychopharmacology – Clinical and Experimental*, *16*(8), 557–577.
- Pascual-Marqui, R. D., Michel, C. M., & Lehmann, D. (1995). Segmentation of brain electrical activity into microstates: Model estimation and validation. *IEEE Transactions on Biomedical Engineering*, *42*, 658–665.
- Paulson, O. B. & Sharbrough, F. W. (1974). Physiological and pathophysiological relationship between the EEG and the cerebral blood flow. *Acta Neurologica Scandinavica*, *50*(2), 194–220.
- Pekala, R. J. (1991). *Quantifying consciousness: An empirical approach*. New York: Plenum.

- Peper, E. (1971). Feedback regulation of the alpha electroencephalogram activity through control of the internal and external parameters. In: T. X. Barber, L. V. DiCara, J. Kamiya, N. E. Miller, D. Shapiro, & J. Stoyva, (Eds.). *Biofeedback and self-control* (pp. 314–332). Chicago: Aldine Atherton.
- Persinger, M. A. (1983). Religious and mystical experiences as artifacts of temporal lobe function: A general hypothesis. *Perceptual and Motor Skills*, 57, 1255–1262.
- Persinger, M. A. (1999). Near-death experience and ecstasy: A product of the organization of the human brain? In S. Della Sala (Ed.), *Mind myths: Exploring popular assumptions about the mind and brain* (pp. 85–99). Chichester, England: Wiley.
- Pessah, M. A. & Roffwarg, H. P. (1972). Spontaneous middle ear muscle activity in man: A rapid eye movement sleep phenomenon. *Science*, 178, 773–776.
- Peterson, C. B., & Mitchell, J. E. (1999). Psychosocial and pharmacological treatment of eating disorders: A review of research findings. *Journal of Clinical Psychology*, 55(6), 685–697.
- Pézard, L., Nandrino, J. L., Renault, B., Massioui, F. E., Allilaire, F., Muller, J., Varela, F. J., & Martinerie, J. (1996). Depression as a dynamical disease. *Biological Psychiatry*, 39, 991–999.
- Pilon, M. & Sullivan, S. J. (1996). Motor profile of patients in minimally responsive and persistent vegetative state. *Brain Injury*, 10(6), 421–437.
- Plotkin, W. B. (1976). On the self-regulation of the occipital alpha-rhythm: Control strategies, states of consciousness, and the role of physiological feedback. *Journal of Experimental Psychology: General*, 105, 66–99.
- Pope, K. S. & Singer, J. L. (1978). *The stream of consciousness*. London: Plenum.

- Preissl, H., Flor, H., Lutzenberger, W., Duffner, F., Freudenstein, D., Grote, E., Birbaumer, N. (2001). Early activation of the primary cortex without conscious awareness. *Neuroscience Letters*, 308, 193–196
- Pritchard, W. S. (1997). A tutorial review of the use and benefits of non-linear dynamical analysis of the EEG. In: F. Angeleri, S. Butler, S. Giaquinto, & J. Majkowski (Eds.), *Analysis of the electrical activity of the brain* (pp. 3–44). New York: Wiley.
- Purcell, S., Moffitt, A. & Hoffmann, R. (1993). Waking, dreaming, and self-regulation. In A. Moffitt, M. Kramer & R. Hoffmann (Eds.), *The functions of dreaming* (pp. 197-260). Albany: State University of New York Press.
- Raab, J. & Gruzelier, J. (1994). A controlled investigation of right hemispheric processing enhancement after restricted environmental stimulation (REST) with floatation. *Psychological Medicine*, 24(2), 457–462.
- Rainville, P., Carrier, B., Hofbauer, R. K., Bushnell, M. C. & Duncan, G. H. (1999). Dissociation of sensory and affective dimensions of pain using hypnotic modulation. *Pain*, 82, 159–171 .
- Rau, H., Pauli, P., Brody, S., Elbert, T., & Birbaumer, N. (1993). Baroreceptor stimulation alters cortical activity. *Psychophysiology*, 30, 322–325.
- Rauch, S. L., Shin, L. M., Dougherty, D. D., Alpert, N. M., Orr, S. P., Lasko, M., Macklin, M. L., Fischman, A. J., & Pitman, R. K. (1999). Neural activation during sexual and competitive arousal in healthy men. *Psychiatry Research*, 91, 1–10.
- Ray, W. J. (1997). EEG concomitants of hypnotic susceptibility. *International Journal of Clinical and Experimental Hypnosis*, 45, 301–313.
- Rechtschaffen, A. & Kales, A. (1968). *A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects*. Public Health Service, U.S. Government Printing Office, Washington, D.C.

- Redouté, J., Stoléru, S., Grégoire, M.-C., Costes, N., Cinotti, L., Lavenne, F., Bars, D. L., Forest, M. G., & Pujol, J.-F. (2000). Brain processing of visual stimuli in human males. *Human Brain Mapping, 11*, 162–177.
- Ritz, T. & Dahme, B. (1995). Die Absorption-Skala: Konzeptuelle Aspekte, psychometrische Kennwerte und Dimensionalität einer deutschsprachigen Adaptation. *Diagnostica, 41*(1), 53–61.
- Rockstroh, B., Elbert, T., Birbaumer, N., Wolf, P., Düchting-Röth, A., Reker, M., Daum, I., Lutzenberger, W. & Dichgans, J. (1993). Cortical self-regulation in patients with epilepsies. *Epilepsy Research, 14*, 63–72.
- Rockstroh, B., Elbert, T., Canavan, A., & Birbaumer, N. (1989). *Slow brain potentials and behavior*. Baltimore: Urban.
- Roffwarg, H. P., Dement, W. C., Muzio, J. N. & Fisher, C. (1962). Dream imagery: Relationship to rapid eye movements of sleep. *Archives of General Psychiatry, 1*, 235–258.
- Rolls, E. T. (1999). *The Brain and Emotion*. Oxford: Oxford University Press.
- Röschke, J. & Aldenhoff, J. (1991). The dimensionality of human's electroencephalogram during sleep. *Biological Cybernetics, 64*, 307–313.
- Rouget, G. (1980). *La musique et la transe*. Paris: Gallimard.
- Rudolf, J. (2000). Beitrag der Positronen-Emissionstomographie zur diagnostischen Zuordnung und prognostischen Einschätzung postanoxischer Hirnschäden. *Fortschritte der Neurologie und Psychiatrie, 68*(8), 344–351.
- Saavedra-Aquilar, J. C. & Gomez-Jeria, J. S. (1989). A neurobiological model for near-death experiences. *Journal of Near-Death Studies, 7*(4), 205–222.



- Saito, N., Kuginuki, T., Yagyu, T., Kinoshita, T., Koenig, T., Pascual-Marqui, R. D., Kochi, K., Wackermann, J., & Lehmann, D. (1998). Global, regional and local measures of complexity of multichannel EEG in acute, neuroleptic-naive, first-break schizophrenics. *Biological Psychiatry, 43*, 794–802.
- Saugstad, L. F. (1994). The maturational theory of brain development and cerebral excitability in the multifactorially inherited manic-depressive psychosis and schizophrenia. *International Journal of Psychophysiology, 18*, 189–203.
- Saver, J. L., & Rabin, J. (1997). The neural substrates of religious experience. *Journal of Neuropsychiatry and Clinical Neuroscience, 9*, 498–510.
- Schacter, D. L. (1976). The hypnagogic state : A critical review of the literature. *Psychological Bulletin, 83*(3), 452–481.
- Schroeter-Kunhardt, M. (1993). A review of near death experiences. *Journal of Scientific Exploration, 7*(3), 219–239.
- Schulman, C. A., Richlin, M., & Weinstein, S. (1967). Hallucinations and disturbances of affect, cognition, and physical state as a function of sensory deprivation. *Perceptual and Motor Skills, 25*, 1001–1024.
- Schulz, P. & Kaspar, C. H. (1994). Neuroendocrine and psychological effects of restricted environmental stimulation technique in a flotation tank. *Biological Psychology, 37*(2), 161–175.
- Schwab, R. J. (1994). Disturbances of sleep in the intensive care unit. *Critical Care Clinics, 10*(4), 681–694.
- Schwartz, M. S. (1995). Breathing Therapies. In: M. S. Schwartz and Associates: *Biofeedback. A practitioners's guide. 2nd ed* (pp. 248–287). New York: Guildford.
- Schwartz, M. S. and Associates (Eds.) (1995). *Biofeedback. A practitioners's guide. 2nd ed.* New York: Guildford.

- Shapiro, S. & Lehrer, P.M. (1980). Psychophysiological effects of autogenic training and progressive relaxation. *Biofeedback and Self-Regulation*, 5(2), 249–255.
- Sheehan, P. W. (1992) The phenomenology of hypnosis and the Experiential Analysis Technique. In E. Fromm & M. R. Nash (Eds.) *Contemporary hypnosis research* (pp. 364–389). New York: Guilford.
- Sheehan, P. W. & McConkey, K. M. (1982). *Hypnosis and experience: The exploration of phenomena and process*. Hillsdale, NJ: Erlbaum.
- Sherwood, S. (2002). Relationship between the hypnagogic/hypnopompic states and reports of anomalous experiences. *Journal of Parapsychology*, 66, 127–150.
- Shimizu, A. & Inoue, T. (1986). Dreamed speech and speech muscle activity. *Psychophysiology*, 23, 210–214.
- Silberer, H. (1909). Bericht über eine Methodik, gewisse symbolische Halluzinations-Erscheinungen hervorzurufen und zu beobachten. *Jahrbuch für Psychoanalytische und Psychopathologische Forschung*, 1, 513–525.
- Smith, J. C., Amutio, S., Anderson, J. P., & Aria, L.A. (1996). Relaxation: Mapping an uncharted world. *Biofeedback and Self-Regulation*, 21(1), 63–90.
- Snyder, S. H. (1996). *Drugs and the Brain*. New York: Scientific American Books.
- Solms, M. (1997). *The neuropsychology of dreams. A clinico-anatomical study*. Mahwah, NJ: Erlbaum.
- Spanos, N. P. (1986) Hypnotic behavior: A social-psychological interpretation of amnesia, analgesia, and „trance logic”. *The Behavioral and Brain Sciences*, 9, 449–502.
- Special Issue On Sleep And Dreaming (2000). *Behavioral and Brain Sciences*, 23, 6.
- Stampi, C., Stone, P., & Michimori, A. (1993). The alpha attenuation test: a new quantitative method for assessing sleepiness and its relationship to the MSLT. *Sleep Research*, 22, 115.

- Stancak, A., Hömig, J., Wackermann, J., Lepicovska, V., & Dostalek, C. (1991). Effects of unilateral nostril breathing on respiration, heart rhythm and brain electrical activity. *Neurosciences, 17*, 409–417.
- Steinhart, M. J. (1978). Treatment of delirium – a reappraisal. *International Journal of Psychiatry in Medicine, 9*(2), 191–197.
- Sterman, M. B. & Shouse, M. N. (1980). Quantitative analysis of training, sleep EEG and clinical response to EEG operant conditioning in epileptics. *Electroencephalography and Clinical Neurophysiology, 49*, 558–576.
- Sterman, M. B. (1996). Epilepsy and its treatment with EEG biofeedback. *Annals of Behavioral Medicine, 8*, 21–25.
- Sterman, M.B. (1977). Effects of sensomotor EEG feedback training on sleep and clinical manifestations of epilepsy. In J. Beatty & H. Legewie (Eds.), *Biofeedback and behaviour* (pp. 167–200). New York: Plenum.
- Strauch, I. & Meier, B. (1996). *In search of dreams*. Albany: State University of New York Press.
- Strauss, D. J., Ahwal, S., Day, S. M., & Shavelle, R. M. (2000). Life expectancy of children in vegetative and minimally conscious states. *Pediatrics and Neurology, 23*, 312–319.
- Strelets, V., Faber, P. L., Golikova, J., Novototsky-Vlasov, V., Koenig, T., Guinotti, I. R. R., Gruzelier, J.H. & Lehmann, D. (2003). Chronic schizophrenics with positive symptomatology have shortened EEG microstate durations. *Clinical Neurophysiology, 14*(11), 2043–2051.
- Strik, W.K. & Lehmann, D. (1993). Data-determined window size and space-oriented segmentation of spontaneous EEG map series. *Electroencephalography and Clinical Neurophysiology, 87*, 169–174.

- Suedfeld, P. & Eich, E. (1995). Autobiographical memory and affect under conditions of reduced environmental stimulation. *Journal of Environmental Psychology*, 15(4), 321–326.
- Suedfeld, P. (Ed.). (1980). *Restricted environmental stimulation. Research and clinical applications*. New York: Wiley.
- Suedfeld, P., Metcalfe, J., & Bluck, S. (1987). Enhancement of scientific creativity by flotation REST (restricted environmental stimulation technique). *Journal of Environmental Psychology*, 7(3), 219–231.
- Suedfeld, P., Ramirez, C. E., Remick, R. A., & Fleming, J. A. (1989). Reduction of post-ECT memory complaints through brief, partial restricted environmental stimulation (REST). *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, 13(5), 693–700.
- Sugimoto, S., Kida, M., Teranishi, T., & Yamamoto, A. (1968). Time estimation during prolonged sensory deprivation. *Japanese Journal of Aerospace Medicine and Psychology*, 6(1), 1–5.
- Szelenberger, W., Wackermann, J., Skalski, M., Niemcewicz, S., & Drojewski, J. (1996). Analysis of complexity of EEG during sleep. *Acta Neurobiologiae Experimentalis*, 56, 165–169.
- Tart, C. T. (1975). *States of consciousness*. New York: Dutton.
- Tart, C. T. (1980). A systems approach to altered states of consciousness. In J. M. Davidson & R. J. Davidson (Eds.), *The psychobiology of consciousness* (pp. 243–270). New York: Plenum.
- Tellegen, A. & Atkinson, G. (1974). Openness to absorbing and self-altering experiences („absorption”), a trait related to hypnotic susceptibility. *Journal of Abnormal Psychology*, 83(3), 268–277.

- Terekhin, P. I. (1996). The role of hypoxia in inducing altered states of consciousness. *Human Physiology*, 22(6), 730–735.
- Terzian, H., & Dalle Ore, G. (1955). Syndrome of Klüver and Bucy reproduced in man by bilateral removal of the temporal lobes. *Neurology*, 5(6), 373–380.
- Tetzlaff, K., Friege, L., Hutzemann, A., Reuter, M., Hoell, D., & Lepow, B. (1999). Magnetic resonance signal abnormalities and neuropsychological deficits in elderly compressed-air divers. *European Neurology*, 42(4), 194–199.
- Thornberg, S. A., Saklad, S. R. (1996). A review of NMDA receptors and the phencyclidine model of schizophrenia. *Pharmacotherapy*, 16, 82–93.
- Tiihonen, J., Kuikka, J., Kupila, J., Vainio, P., Airaksinen, J., Eronen, M., Hallikainen, T., Paanila, J., & Kinnunen, I. (1994). Increase in cerebral blood flow of right prefrontal cortex in man during orgasm. *Neuroscience Letters*, 170, 241–243.
- Tisher, P. W., Holzer, J. C., Greenberg, M., Benjamin, S., Devinsky, O., & Bear, D. M. (1993). Psychiatric presentations of epilepsy. *Harvard Review of Psychiatry*, 1, 218–219.
- Toga, A. W. & Mazziotta, S. C. (2000). *Brain Mapping*. San Diego: Academic Press.
- Tommasino, C., Grana, C., Lucignani, G., Torri, G., & Fazio, F. (1995). Regional cerebral metabolism of glucose in comatose and vegetative state patients. *Journal of Neurosurgery and Anesthesiology*, 7, 109–116.
- Tononi, G. & Edelman, G. M. (1998). Consciousness and Complexity. *Science*, 282, 1846–1851
- Tononi, G. & Edelman, G. M. (2000). Schizophrenia and the mechanisms of conscious integration. *Brain Research Interactive*, 31, 391–400.
- Travis, F. & Wallace, R. K. (1997). Autonomic patterns during respiratory suspensions: Possible markers of transcendental consciousness. *Psychophysiology*, 34, 39–46.

- Travis, F. T. (1993). Respiratory, autonomic, and EEG correlates of transcendental consciousness experiences during Transcendental Meditation practice. *Society for Neuroscience Abstracts*, 18(1), 574: 15.
- Tucker, D. M. & Dawson, S. L. (1984). Asymmetric EEG changes as method actors generated emotions. *Biological Psychology*, 19, 63–75.
- Turner, J. W. & Fine, T. H. (1983). Effects of relaxation associated with brief restricted environmental stimulation therapy (REST) on plasma cortisol, ACTH, and LH. *Biofeedback and Self-Regulation*, 9, 115–126.
- Turner, J. W., Fine, T., Ewy, G., Sershon, P., & Freundlich, T. (1989). The presence or absence of light during flotation restricted environmental stimulation: Effects on plasma cortisol, blood pressure, and mood. *Biofeedback and Self Regulation*, 14(4), 291–300.
- Uleman, J. S. & Bargh, J. A. (Eds.) (1989). *Unintended thought*. New York: Guilford.
- Ulrich, G. & Gschwilm, R. (1988). Vigilanz – Ordnungszustand oder ordnende Kraft? *Fortschritte der Neurologie und Psychiatrie*, 56, 398–402.
- Vaitl, D. & Gruppe, H. (1995). CNS modulation induced by hemodynamic changes. In D. Vaitl & R. Schandry (Eds.), *From the heart to the brain. The psychophysiology of circulation-brain interaction* (pp. 89–104). Frankfurt a. M.: Lang.
- Vaitl, D., Sammer, G., & Ott, U. (2000). Rhythmic tilting controlled by respiration: Effects on heart rate, EEG, basic information processing, and consciousness. *International Journal of Psychophysiology*, 35(1), 41.
- Varela, F. J., Lachaux, J., Rodriguez, E., & Martinerie, J. (2001). The brainweb: Phase synchronization and large-scale integration. *Nature Reviews Neuroscience*, 2, 229–239.
- Vasquez, E. & Chitwood, W. R. (1975). Postcardiotomy delirium: An overview. *International Journal of Psychiatry in Medicine*, 6(3), 373–383.

- Vernon, D., Egner, T., Cooper, N., Compton, T., Neilands, C., Sheri, A., & Gruzelier, J. H. (2003). The effect of training distinct neurofeedback protocols on aspects of cognitive performance. *International Journal of Psychophysiology*, *47*, 75–85.
- Vollenweider, F. X. & Geyer, M. A. (2001). A systems model of altered consciousness: Integrating natural and drug-induced psychosis. *Brain Research Bulletin*, *56*(5), 495–507.
- Vuilleumir, P., Despland, P. A., Assal, G., & Regli, F. (1997). Voyages astraux et hors du corps. Heautoscopie, extase et hallucinations experientielles d'origine epileptique. *Revue Neurologique*, *153*, 115–119.
- Wackermann, J. (1996). Beyond mapping: Estimating complexity of multichannel EEG recordings. *Acta Neurobiologiae Experimentalis*, *56*, 197–208.
- Wackermann, J. (1999). Towards a quantitative characterisation of functional states of the brain: From the non-linear methodology to the global linear description. *International Journal of Psychophysiology*, *34*, 65–80.
- Wackermann, J., Lehmann, D., Michel, C. M., & Strik, W. K. (1993). Adaptive segmentation of spontaneous EEG map series into spatially defined microstates. *International Journal of Psychophysiology*, *14*, 269–283.
- Wackermann, J., Pütz, P., & Braeunig, M. (2002). EEG correlates of ganzfeld-induced hallucinatory experience. *International Journal of Psychophysiology*, *45*, 17.
- Wackermann, J., Pütz, P., & Miener, M. (2001). EEG correlates of distorted time experience: frequency bands and topography. *Brain Topography*, *13*, 326.
- Wackermann, J., Pütz, P., Büchi, S., Strauch, I., & Lehmann, D. (2000). A comparison of Ganzfeld and hypnagogic state in terms of electrophysiological measures and subjective experiences. *Proceedings of the 43rd P.A. Convention, August 17–20, 2000, Freiburg, Germany*, pp. 302–315.

- Wackermann, J., Pütz, P., Büchi, S., Strauch, I., & Lehmann, D. (2002). Brain electrical activity and subjective experience during altered states of consciousness: Ganzfeld and hypnagogic states. *International Journal of Psychophysiology*, *46*, 122–145.
- Wade, D. T. & Johnston, C. (1999). The permanent vegetative state: Practical guidance on diagnosis and management. *British Medical Journal*, *319*, 841–844.
- Wagstaff, G. F. (1998) The semantics and physiology of hypnosis as an altered state: Towards a definition of hypnosis. *Contemporary Hypnosis*, *15*, 149–165.
- Weinberg W. A. & Harper, C. R. (1993). Vigilance and its disorders. *Behavioral Neurology*, *1*, 59–78.
- Wertheimer, M. (1923). Untersuchungen zur Lehre von der Gestalt. *Psychologische Forschung* *4*, 301–350. [Engl. transl. *Laws of Organization in Perceptual Forms* in W. Ellis, *A Source Book of Gestalt Psychology*. London: Routledge & Kegan Paul, 1938; pp. 71–88.]
- Whinery, J. E. (1997). Psychophysiological correlates of unconsciousness and near-death experiences. *Journal of Near-Death Studies*, *15*(4), 231–258.
- Whyte, J., DiPasquale, M. C., & Vaccaro, M. (1999). Assessment of command-following in minimally conscious brain injured patients. *Archives of Physical Medicine and Rehabilitation*, *80*, 653–660.
- Williams, J. D. & Gruzelier, J. H. (2001). Differentiation of hypnosis and relaxation by analysis of narrow band theta and alpha frequencies. *International Journal of Clinical and Experimental Hypnosis*, *49*, 185–206.
- Wiseman, R. & Milton, J. (1999). Does psi exist? Lack of replication of an anomalous process of information transfer. *Psychological Bulletin*, *125*, 387–391.
- Wood, J. A., Lugg, D. J., Hysong, S. J., & Harm, D. L. (1999). Psychological changes in hundred-day remote Antarctic field groups. *Environment and Behavior*, *31*, 299–337.



Woodworth, R.S. & Schlosberg, H. (1954). *Experimental Psychology*. New York: Holt.

Woody, E.Z. & McConkey, K.M. (2003). What we don't know about the brain and hypnosis but need to: A view from the Buckhorn Inn. *International Journal of Clinical and Experimental Hypnosis*, 51, 309–338.

Zeitlhofer, J., Steiner, M., Oder, W., Obergottsberger, S., Mayr, N., & Deecke, L. (1991). Prognostische Wertigkeit evozierter Potentiale in der neurologischen Frührehabilitation bei Patienten im apallischen Syndrom. *Zeitschrift für EEG – EMG*, 22, 10–14.

Zeman, A. (2001). Consciousness. *Brain*, 124, 1263–1289.

Zubek, J. P. (1969). *Sensory deprivation: Fifteen years of research*. New York: Appleton-Century-Crofts.

Zubek, J. P., Hughes, G. R., & Shephard, J. M. (1971). A comparison of the effects of prolonged sensory deprivation and perceptual deprivation. *Canadian Journal of Behavioural Science*, 3(3), 282–290.

Zuckerman, M., Persky, H., & Link, K. E. (1969). The influence of set and diurnal factors on autonomic responses to sensory deprivation. *Psychophysiology*, 5(6), 612–624.

## Footnotes

## Footnote 1

Only EEG and MEG allow for the time resolution to observe on-line changes of mental processes, both reflecting summation of synchronized synaptic inflow to apical dendrites of the cortex. While EEG originates from vertically oriented pyramidal cell columns, MEG reflects tangential electromagnetic dipoles mainly located in the cortical sulci. Spatial resolution of EEG/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 only be visualized 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 to specify 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 Methods of Induction*

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**1. Spontaneously occurring**

1.1 States of drowsiness

1.2 Daydreaming

1.3 Hypnagogic states

1.4 Sleep and dreaming

1.5 Near-death experiences

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**2. Physically and physiologically induced**

2.1 Extreme environmental conditions (pressure, temperature)

2.2 Starvation and diet

2.3 Sexual activity/orgasm

2.4 Respiratory maneuvers

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**3. Psychologically induced**

3.1 Sensory deprivation, homogenization and overload

3.2 Rhythm-induced trance (drumming, dancing)

3.3 Relaxation

3.4 Meditation

3.5 Hypnosis

3.6 Biofeedback

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**4. Disease induced**

4.1 Psychotic disorders

4.2 Coma, vegetative state

4.3 Epilepsy

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**5. Pharmacological induced (not reviewed)**

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Table 2: *Phenomenological Dimensions of Altered States of Consciousness*

Induction method	Activation	Awareness	Self-	Sensory
	+ aroused – relaxed	span + wide – narrow	awareness + present – absent	dynamics + increased – decreased
1.1 States of drowsiness	–	–	+/-	–
1.2 Daydreaming	–	–	+	+
1.3 Hypnagogic states	–	–	+	+
1.4 Sleep and dreaming	–	+	+	+
1.5 Near-death experiences	–	–	+	+
2.1 Extreme environmental conditions	+	–	+	+
2.2 Starvation and diet	+	–	+	–
2.3 Sexual activity/orgasm	+	–	–	–
2.4 Respiratory maneuvers	–	–	+	–
3.1a Sensory deprivation	–	+	+/-	–
3.1b Sensory homogenization	–	+/-	+/-	+
3.1c Sensory overload	+	–	–	+
3.2 Rhythm-induced trance	+	+	–	+
3.3 Relaxation	–	–	+	–
3.4 Meditation	+/-	+/-	+/-	+/-
3.5 Hypnosis	+/-	+/-	+/-	+/-
3.6 Biofeedback	+/-	+/-	+/-	+/-
4.1 Psychotic disorders	+/-	+/-	–	+/-
4.2 Coma, vegetative state	–	–	–	–
4.3 Epilepsy	+	–	–	+/-

Table 3: *Neuroanatomical Substrates of Attention and Arousal (often called „limited capacity control system”, LCCS)*

<b>Neuroanatomical system</b>	<b>Function</b>	<b>Consequences of lesion</b>
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 („re-entrant” cortico-thalamic 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 (soziopathy)
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)

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

Organizational level	Techniques, methods, conditions
6. Self-control	biofeedback, hypnosis, meditation, relaxation
5. Arousal	drowsiness, hypnagogic states, sleep, dreaming
4. Sensory input, environment	rhythmic stimulation, sensory deprivation and homogenization
3. Neurochemical and metabolic processes	hyperventilation, starvation/diet, near-death experiences
2. Brain dynamics	epilepsy, psychotic disorders
1. Structural (brain tissue)	coma

Figure Captions

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

