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ALTERATIONS IN THE STATES AND CONTENTS OF CONSCIOUSNESS: EMPIRICAL AND THEORETICAL ASPECTS

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ABSTRACT

The main purpose of the present doctoral thesis is to investigate subjective experiences and cognitive processes in four different types of altered states of consciousness: naturally occurring dreaming, cognitively induced hypnosis, pharmacologically induced sedation, and pathological psychosis. Both empirical and theoretical research is carried out, resulting in four empirical and four theoretical studies. The thesis begins with a review of the main concepts used in consciousness research, the most influential philosophical and neurobiological theories of subjective experience, the classification of altered states of consciousness, and the main empirical methods used to study consciousness alterations. Next, findings of the original studies are discussed, as follows. Phenomenal consciousness is found to be dissociable from responsiveness, as subjective experiences do occur in unresponsive states, including anaesthetic-induced sedation and natural sleep, as demonstrated by post-awakening subjective reports. Two new tools for the content analysis of subjective experiences and dreams are presented, focusing on the diversity, complexity and dynamics of phenomenal consciousness. In addition, a new experimental paradigm of serial awakenings from non-rapid eye movement sleep is introduced, which enables more rapid sampling of dream reports than has been available in previous studies. It is also suggested that lucid dreaming can be studied using transcranial brain stimulation techniques and systematic analysis of pre-lucid dreaming. For blind judges, dreams of psychotic patients appear to be indistinguishable from waking mentation reports collected from the same patients, which indicates a close resemblance of these states of mind. However, despite phenomenological similarities, dreaming should not be treated as a uniform research model of psychotic or intact consciousness. Contrary to this, there seems to be a multiplicity of routes of how different states of consciousness can be associated. For instance, seemingly identical time perception distortions in different alterations of consciousness may have diverse underlying causes for these distortions. It is also shown that altered states do not necessarily exhibit impaired cognitive processing compared to a baseline waking state of consciousness: a case study of time perception in a hypnotic virtuoso indicates a more consistent perceptual timing under hypnosis than in a waking state. The thesis ends with a brief discussion of the most promising new perspectives for the study of alterations of consciousness.

Keywords: altered state of consciousness, baseline state of consciousness, content analysis, distortions of time perception, dreaming, hypnosis, perception of duration, phenomenal consciousness, psychosis, sedation, sleep, stream of consciousness, subjective experience, wakefulness.

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Cambridge, 9 September 2014

Valdas Noreika

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications, which are referred to in the text by their Roman numerals.

Empirical studies

I Noreika, V., Jylhänkangas, L., Móró, L., Valli, K., Kaskinoro, K., Aantaa, R., Scheinin, H., & Revonsuo, A. (2011a). Consciousness lost and found: Subjective experiences in an unresponsive state. *Brain and Cognition, 77*, 327–334.[a]

II Noreika, V., Valli, K., Lahtela, H., & Revonsuo, A. (2009). Early-night serial awakenings as a new paradigm for studies on NREM dreaming. *International Journal of Psychophysiology, 74*, 14–18.[a]

III Noreika, V., Valli, K., Markkula, J., Seppälä, K., & Revonsuo, A. (2010a). Dream bizarreness and waking thought in schizophrenia. *Psychiatry Research, 178*, 562–564.[a]

Theoretical studies

IV Noreika, V. (2011). Dreaming and waking experiences in schizophrenia: How should the (dis)continuity hypotheses be approached empirically? *Consciousness and Cognition, 20*, 349–352.[a]

V Windt, J. M., & Noreika, V. (2011). How to integrate dreaming into a general theory of consciousness – A critical review of existing positions and suggestions for future research. *Consciousness and Cognition, 20*, 1091-1107.[a]

VI Noreika, V., Windt, J. M., Lenggenhager, B., & Karim, A. A. (2010b). New perspectives for the study of lucid dreaming: From brain stimulation to philosophical theories of self-consciousness*. International Journal of Dream Research, 3*, 36–45.[b]

Empirical study

VII Noreika, V., Falter, C. M., Arstila, V., Wearden, J. H., & Kallio, S. (2012). Perception of short time scale intervals in a hypnotic virtuoso. *International Journal of Clinical and Experimental Hypnosis, 60*, 318–337.[c]

Theoretical study

VIII Noreika, V., Falter, C. M., & Wagner, T. (2014). Variability of duration perception: From natural and induced alterations to psychiatric disorders. V. Arstila & D. Lloyd (Eds.), *Subjective Time: The Philosophy, Psychology, and Neuroscience of Temporality* (pp. 529-555). Cambridge, MA: MIT Press.[d]

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LIST OF ABBREVIATIONS

ASC	altered state of consciousness
BIS index	bispectral index
EEG	electroencephalography
EMG	electromyography
ENSA	early-night serial awakenings
EOG	electrooculography
fMRI	functional magnetic resonance imaging
DLPFC	dorsolateral prefrontal cortex
LOR	loss of responsiveness
LSD	lysergic acid diethylamide
M	mean
MEG	magnetoencephalography
NREM sleep	non-rapid eye movement sleep
O-PC-Dreams	Orlinsky's Modified Scale for Perceptual Complexity of Dreams
PCI	perturbational complexity index
PSG	polysomnography
REM sleep	rapid eye movement sleep
ROR	regaining of responsiveness
SCSB	static charge sensitive bed
SD	standard deviation
SEDA-Coding	Subjective Experiences During Anaesthesia Coding System
tDCS	transcranial direct current stimulation
TMS	transcranial magnetic stimulation

1. INTRODUCTION

Human individuals are unique in the momentary and lifelong collection of their contents of consciousness, or subjective experiences, which include – but are not limited to – sensations, feelings, thoughts, and beliefs. Typically, the contents of consciousness are complex and dynamic, with an extremely wide range of possible experiences that continuously adapt to internal and external stimuli as well as to other subjective experiences. While in standard social situations we are relatively successful in guessing subjective experiences of other individuals by drawing inferences from their behaviour and affective display (Ames, 2005), it proves to be very difficult to measure the contents of consciousness with scientific methods. The task becomes even more complicated when a participant undergoes an alteration of consciousness, such as during the transition from waking consciousness to sleep dreaming. The most challenging task is a scientific assessment of subjective experiences of an individual who loses capacity to respond in an altered state of consciousness (ASC), such as during sleep or general anaesthesia. Nevertheless, any general theory of consciousness and its neural basis should also describe, predict and explain the alterations of consciousness that happen under different circumstances.

The problem of the detection of consciousness can be addressed with objective methods, such as the functional magnetic resonance imaging (fMRI), with subjective methods, such as analysis of verbal reports and questionnaires, or with a combination of both types of methods. For instance, analysis of neurophysiological data can make it possible to distinguish which of the two competing images participants perceive in the binocular rivalry paradigm (Haynes & Rees, 2005), or to evaluate if an unresponsive vegetative state patient follows mental imagery-related instructions (Owen et al., 2006). In a recent study, machine-learning-based analysis of fMRI data even enabled prediction above chance level of the visual contents of non-rapid eye movement (NREM) sleep dreaming (Horikawa et al., 2013). Yet, despite an invaluable progress, studies using objective methods are limited by the predictability of the contents of consciousness, i.e., they rely on the recognition of neural activity patterns that emerge in association with the standardized contents of consciousness. For instance, a recent study on dream content detection relied on the neural similarity between relatively simple perceptual experiences in waking and sleep onset (Horikawa et al., 2013), which may not hold for more intense and unpredictable rapid eye movement (REM) sleep dreaming or other unresponsive states of consciousness with complex spontaneously developing subjective experiences. Furthermore, neuroimaging-driven prediction is not explanation, while the ultimate goal of the science of consciousness is the explanation of how subjective experiences arise from brain activity.

Compared to the objective methods, content analysis of subjective reports enables a very detailed assessment of naturally and spontaneously occurring subjective experiences, including, but not limited to, such diverse contents of consciousness as Self and body, visual experiences, perception of sound, temporal and spatial distortions, and so on. Arguably, a detailed mapping of human phenomenology in different states of consciousness will eventually provide a solid ground for research into the neural basis of consciousness. While subjective methods alone are not able to provide sufficient insight into the neural mechanisms of consciousness, a combination of both objective and subjective methods will probably become one of the most promising avenues of consciousness research in the near future. Nevertheless, it is not straightforward to combine subjective and objective methods, and they are still being developed largely separately. Likewise, this dissertation will focus mostly on the application and development of subjective methods, which will be used to describe the phenomenal contents of ASCs.

The main goal of this doctoral thesis was to investigate subjective experiences and cognitive processes in four different alterations of consciousness: dreaming, hypnosis, sedation, and psychosis. Individual studies focused on the development of new experimental paradigms and content analysis methods, systematic comparison of different alterations of consciousness, and contribution to the theoretical issues underlying research of ASCs. In the following sections, after reviewing the main concepts used in consciousness research, the most influential philosophical and neurobiological theories of subjective experience, the classification of ASCs, and the main empirical methods to study consciousness alterations, each of the original studies will be presented in detail.

2. CONSCIOUSNESS

Consciousness science is a multidisciplinary field in the intersection between philosophy, experimental psychology, neuropsychology, and cognitive neuroscience. Given a large number of competing theories and approaches, it is natural that many of the key concepts used in consciousness research, such as *awareness*, *access consciousness* or *unconsciousness*, are often used in different and partly controversial meanings. To minimize conceptual confusion, these terms should be carefully defined, searching for the most accurate match between our semantics and the natural kinds of human mind.

2.1. The key concepts and distinctions

2.1.1. *Phenomenal consciousness*

When scientists and philosophers discuss the hard problem of consciousness (Chalmers, 1995; see Section 2.4), they primarily mean *phenomenal consciousness*, which is the most fundamental term in contemporary research of subjective experiences. The concept of phenomenal consciousness refers to the presence of a subjective aspect in a wide range of mental functions, including perception, emotion, memory, attention, language, decision making, and control of motor output (Block, 1995; Revonsuo, 2006). When we say a word, touch a tablecloth or remember what we have seen during the last trip abroad, these acts are usually accompanied by internal experiences, which are subjective and available only to us. As Nagel (1974) phrased, an organism is conscious if 'there is something it is like to *be* that organism' (p. 436), that is, if it has experiences that bear distinctive subjective qualities – often referred to as *qualia* (Lewis, 1929) – for the organism (see also Section 2.3).

2.1.2. *Sensory awareness*

Phenomenal consciousness is sometimes equated with *awareness*, however, the latter concept is narrower and refers to a special type of phenomenal consciousness: the presence of sensory experiences triggered by real physical stimuli of which we thereby become aware. In particular, each of the classical sensory systems, i.e., vision, hearing, olfaction, gustation and somatosensory system, has not only unique receptive fields, cellular receptors, central pathways and cortical networks (Møller, 2003), but also unique sensory qualities of experience. We not only detect a leaf falling from a tree, but also have a subjective awareness of that leaf, awareness that does not seem necessary for the detection itself. Naturally, phenomenal consciousness within each sensory system is often conceptualized as visual awareness (Koivisto et al., 2006), auditory awareness (Gutschalk et al., 2008), olfactory awareness (Li et al., 2010), gustatory awareness (Verhagen, 2007), or somatosensory awareness (Schubert et al., 2006). Notably, *phenomenal consciousness* as a broader term also includes, for instance, internally generated hallucinatory experiences, or subjective experiences related to non-sensory mental functions, such as semantic processing. That is, *awareness* is a type of phenomenal consciousness triggered by external physical stimuli or internal physiological processes in a case of interoceptive awareness (Critchley et al., 2004), whereas *phenomenal consciousness* refers to the subjective experience itself, regardless of what triggered it, external or internal stimuli, thoughts, or memories.

2.1.3. *Access consciousness, reflective consciousness, cognitive accessibility*

Subjective experiences can be attended to and information about them distributed within a broader neural network for further information processing, leading to various cognitive and behavioural effects. This implicates that phenomenal consciousness can be described functionally. Functional interactions between phenomenal consciousness and broader cognitive systems guiding rational behaviour have been termed as *access consciousness* (Block, 1995). Block (1995) argued for a double dissociation between phenomenal consciousness and access consciousness, i.e., subjective experiences might exist without being broadcasted to the executive processes, whereas functional causal roles of access consciousness may be achieved without the presence of subjective experiences. Revonsuo (1995a, 2006) pointed out that such a definition of access consciousness allows a subjectively unconscious person to be called conscious, leading to a conceptual contradiction. Instead, a theoretically more coherent approach may be a separation of two levels of consciousness: the first fundamental level would be phenomenal consciousness and the second higher level would consist of cognitive operations over selected subjective experiences held in working memory (Revonsuo, 2006). Farthing (1992) termed the second higher-order level as *reflective consciousness*, although this term may be somewhat too narrow, as the concept of reflective consciousness is sometimes described in terms of abstract thinking and verbalization of subjective experiences (Bartolomeo et al., 2008), whereas cognitive operations over phenomenal consciousness also include more basic cognitive processes that are not necessarily verbalized, such as selective attention or difference detection (Revonsuo, 2006). In more recent studies, Block (2007, 2011) toned down the arguments regarding dissociation between phenomenal and access consciousness, and instead of these terms started using the concepts of phenomenology and *cognitive accessibility*, the latter of which is defined as the broadcasting of subjective experiences within the central processing system. The concepts of phenomenology and cognitive accessibility (Block, 2007) seem to be compatible with the distinction between phenomenal and reflective consciousness (Farthing, 1992; Revonsuo, 2006).

2.1.4. *Contents vs. state of consciousness*

Subjective experiences are sometimes termed as *phenomenal contents of consciousness*, which refers to the variety of experiences that are contained or occur in phenomenal consciousness (Revonsuo, 2006). Most of the phenomenal contents of consciousness are also *representational contents*, i.e., they seem to be representing specific aspects of the physical world (Chalmers, 2000). Even though not all subjective experiences have veridical physical referent, for example, some bizarre dream experiences or hallucinations may be unrelated to the actual physical world, they still typically do appear for an experiential subject as representing external reality. The totality of phenomenal contents forms the *state of consciousness*, i.e., an overall pattern of subjective psychological functioning (Tart, 1972). Alongside a theoretical distinction between the presence of specific contents of consciousness and the presence of an overall state of consciousness, two independent neurophysiological research programs are currently developing in the empirical science of consciousness. Research on the phenomenal contents of consciousness focuses on the neural mechanisms of specific subjective experiences, for example, detection of masked visual targets (Mathewson et al., 2009), while ignoring other simultaneously occurring contents of consciousness. By contrast, neuroimaging research of the state of consciousness typically contrasts the conscious state with the loss or the absence of consciousness in conditions such as regaining of consciousness after its loss due to the administration of anaesthetic agents (Långsjö et al., 2012).

2.1.5. *Altered vs. baseline states of consciousness*

Compared to the standard waking state of consciousness, which could be regarded as a *baseline state of consciousness*, human consciousness may undergo various neurocognitive alterations, such as those observed in dreaming, hypnosis or meditation. Such alterations are often referred to as *altered states of consciousness* (ASCs) (Tart, 1975), and they are typically individuated by specific changes in their contents (Chalmers, 2000) and/or their induction techniques (Vaitl et al., 2005) (see Section 3.1). Complementing the classical neurological approach of studying abnormal in order to understand normal, ASCs can be used as important contrast conditions for studying human consciousness and the breakdown of its fundamental properties (Hobson, 2001; Revonsuo, 2006).

2.1.6. *Conscious, unconscious, and nonconscious processes and states*

Phenomenal contents do change rapidly, and a stimulus of which we were aware a couple of seconds ago may not be a part of the current contents of consciousness. Nevertheless, some of the dissipated contents may re-enter phenomenal consciousness after, for instance, episodic memory retrieval (Düzel et al., 1997). By contrast, some other neural processes are never associated with the phenomenal contents of consciousness, for example, the early latency (55 ms) of visual evoked potential C1 (Di Russo et al., 2002) indicates that we are not directly aware of neural processes underlying its generation, as visual awareness-related electroencephalography (EEG) potentials occur in the time latencies above 100 ms (Koivisto & Revonsuo, 2010). Neural activity patterns that are not associated with conscious experiences but could, under some circumstances, produce phenomenal consciousness can be termed as *unconscious contents*, whereas *nonconscious processes* are those deprived of capacity to reach phenomenal consciousness (Searle, 1992). A similar distinction can be drawn between conscious, unconscious and nonconscious states of mind. A *conscious state* would contain at least one subjective experience, whereas *unconscious state*, such as deep NREM sleep, may have no qualia, but would maintain a potential to become conscious if some dream experiences would emerge (see Section 3.6). *Nonconscious states* of the brain/mind are those that have no capacity to support phenomenal consciousness, such as irreversible coma (Silverman et al., 1970). By definition, there are no unconscious contents in the nonconscious state of the brain/mind.

2.2. Fundamental properties of consciousness

Given that subjective experiences accompany a very wide range of sensory, cognitive and behavioural functions, most of which have a large number of sub-functions, phenomenal consciousness turns out to be a very diverse and generic brain process. For instance, not only has each modality of sensory awareness exclusive experiential qualities, but each sensory system codes a large number of unique stimuli features that are associated with unique qualia. Thus, for example, visual awareness is comprised of experiences of colour (Vul & MacLeod, 2006), motion (Eagleman & Sejnowski, 2000), depth (Brouwer et al., 2005), and location (Huang et al., 2007). While simple sensory qualities may accompany the realm of sensory awareness, more complicated experiences of, for instance, understanding and remembering may be associated with complex cognitive functions, such as semantic processing (Kiefer & Spitzer, 2000) or autobiographic memory (Piolino et al., 2003). In the latter cases, subjective experiences do not reflect physical properties of stimuli but instead they point to the higher order phenomenal qualities such as subjective certainty (Tulving, 1985) or an awareness of semantic ambiguities (Zipke et al., 2009).

When focusing on a specific type of subjective experiences in a restricted experimental setup, phenomenal consciousness seems to be a constellation of a vast number of subjective experiences that emerge, develop and vanish in isolation from other experiences. Thus, for example, research on participant's awareness of changing ambiguous Necker cubes (Intaitė et al., 2013), while being an interesting visual phenomenon in itself, seems to have no connection to other subjective experiences that may occur during the same experiment, including feelings of hunger, boredom, or guilt after missing a stimulus, a tingling sensation in a shoulder, hearing of the background noise, or seeing objects in the peripheral visual field. However, introspection of our own experiences reveals that phenomenal consciousness, despite its richness and dynamics, is normally unified and coherent, forming a consistent complex model of external and internal environment (Revonsuo, 2006).

James (1890) argued that there is continuity in the diversity of phenomenal experiences, which can be conceptualized as the *stream of consciousness*, pointing to the constantly changing, yet coherent and continuous, contents of phenomenal consciousness. Continuity of the stream of consciousness depends on the temporal and spatial unity or binding of individual subjective experiences (Dainton, 2006; Revonsuo, 2006). Even though each distinct experience may occur at different points in the phenomenal space and time, they are joined together into a coherent flow of a single unified stream of consciousness. That is, we do not have an experience of unrelated sensations that jump in time and space, although this may take place in certain psychiatric or neurological conditions such as schizophrenia (Vogeley & Kupke, 2007) or akinetopsia (Zeki, 1991), but an experience of spatially and temporally bound qualities that form a single stream of consciousness. The concept of *consciousness-related binding* refers to the experienced phenomenal unity of the contents of consciousness, and it should be demarcated from the *stimulus-related binding*, which refers to the coherence of neural representations of external physical objects that may or may not become the phenomenal contents of consciousness (Revonsuo, 1999, 2006).

In addition to the temporal and spatial binding of phenomenal contents, they are also bound together across different mental domains, including sensory, executive, semantic and motor functions. Such *multifunctional integration* of subjective experiences brings together different types of qualia into a coherent perception of the world, for example, while talking with a friend, we may experience visual awareness of her face, auditory awareness of verbal sounds, and semantic awareness of the meaning of words, which may further surprise us or trigger some autobiographical memories.

2.2.1. *Temporal binding*

Temporal binding of the phenomenal contents of consciousness integrates subjective experiences over time. In phenomenal consciousness, temporal binding can be studied in terms of perception of duration and simultaneity (Kiverstein, 2010). Perception of duration is typically associated with integration of the same set of qualia over time, for example, we may feel that the experience of a bee whose flying trajectory we just followed lasted for a certain interval of time, e.g., 3 seconds. Possibly, the same neuronal populations representing the bee continued oscillating and synchronizing their activity during this period of time (Engel & Singer, 2001), and subjectively we experienced it as a single temporally extended percept of the bee. Interestingly, it has been shown that perceptual or attentional sampling of sensory information is not completely continuous, but instead it oscillates in the theta (4–8 Hz) or alpha (8–12 Hz) frequency range (Busch et al., 2009; Mathewson et al., 2009; Ng et al., 2012). Phenomenally we are not aware of such temporal snapshots underlying our perception, and their mechanisms operate at the nonconscious level of processing (see Section 2.1.6).

While perception of duration is often associated with awareness of a single object, perception of simultaneity points to the integration of several different sets of qualia over time, i.e., we may experience the flying bee and the still honeybush at the same time. Contrary to simultaneity, perception of asynchrony or temporal order reveals a temporal succession of different phenomenal contents of consciousness. In these cases, the temporal binding unifies the change from one subjective experience to another over a wider interval of time. This aspect of temporal binding likely involves neurocognitive mechanisms of phenomenal consciousness: the just-experienced contents of consciousness are kept in the iconic memory, while we experience the present contents, anticipating the subsequent ones. The tripartite temporal structure of consciousness is sometimes referred to as the *specious present* – the temporally extended phenomenal experience of now (Dainton, 2006; Kelly, 1882). The widest temporal binding of phenomenal contents of consciousness depends on the autobiographic memory, which integrates phenomenal experiences over many days and years, constituting the basis for *self-consciousness*, also called *autonoetic consciousness* (Piolino et al., 2003; Tulving, 1985; Wheeler et al., 1997).

2.2.2. *Spatial binding*

Spatial binding of the phenomenal contents of consciousness refers to the integration of subjective experiences in space. Each stimulus-driven experience has a specific location in relation to other experiences, which is studied under the concept of *location binding* (Treisman, 1996). Furthermore, experiences typically have a defined location with respect to our own body that forms the centre of phenomenal space (Revonsuo, 2006). The egocentric reference point is typically located in the phenomenal head or chest and it can be used to identify the location of other phenomenal contents of consciousness (Revonsuo, 2006). Phenomenal spatiality, while typically studied in the visual domain (Clark, 2000), is inherent not only for every sensory modality but also for emotions and feelings (Nummenmaa et al., 2014). While visual and auditory experiences are typically localized in the phenomenal space outside our bodily space, tactile or emotional stimuli are primarily located within the phenomenal body. Notably, various experimental manipulations can reallocate experiences from the external phenomenal space to the internal bodily space or vice versa. For example, identical auditory stimuli presented binaurally through the headphones might be subjectively felt as localized inside the head (Hartmann & Wittenberg, 1996), whereas presentation of conflicting visual-somatosensory input in virtual reality may shift the self-centre outside of the physical body (Lenggenhager et al., 2007). Nevertheless, spatial unity of experiences is maintained even in such unexpected and artificial distortions, indicating the robustness of consciousness-related spatial binding.

2.2.3. *Multifunctional integration*

In addition to the temporal and spatial binding, phenomenal consciousness is integrated across different perceptual, cognitive and behavioural functions, leading to the multifunctional unity of the experience of the self in the world. Such *multifunctional integration* takes place along several different axes, including perception-perception, perception-language, and perception-action unity. For instance, integration of phenomenal contents across different sensory systems (e.g., seeing a face and hearing its speech), brings together very different perceptual qualia under one single stream of consciousness instead of forming two separate auditory and visual streams of phenomenal contents. Furthermore, conscious awareness itself may have a crucial role in such *multisensory interactions*, as in some cases only consciously perceived information from the dominating sensory modality is transferred to another modality (Palmer & Ramsey, 2012). Multisensory interactions between different sensory modalities may also underlie generation of spatial awareness (Clavagnier et al., 2004) and bodily self-consciousness (Blanke, 2012). Another type of multifunctional integration takes place in the form of *perceptual-semantic binding*, which enables the experience of the immediate meaningfulness of phenomenal contents of consciousness (Revonsuo, 2006). Typically, perceptual experiences are automatically bound together with semantic contents, leading to the spontaneously occurring recognition and linguistic conceptualization of these experiences.

The first-person perspective suggests that ‘we see the very world we act in and we act in the world we see’ (Clark, 2009, p. 1460). If so, the integration of perception and action along a single unified flow of body-world interaction might be another fundamental aspect of consciousness, which has even been suggested to be the ontological basis of consciousness (O'Regan & Noë, 2001). Indeed, embodied vision seems to be dominating over subjective experiences during wakefulness, when we perceive and interact with the world around us. However, bodily and motor processes do not seem to be necessary for visual experiences to emerge, as, for instance, people may have rather intense visual dreams during REM sleep, when their muscular system is atonic. Furthermore, the neuropsychological and neuroimaging evidence suggests that conscious ‘vision for perception’ in the ventral visual processing stream and non-conscious ‘vision for action’ in the dorsal stream can be dissociated from each other

(Goodale & Milner, 1992; Milner & Goodale, 2008). Thus, perception-action integration seems to be a typical, but not a fundamental property of consciousness.

2.3. The hard problem of subjectivity

Given that phenomenal contents of consciousness are subjective and directly available only to the experiencing self, explaining the ontology of consciousness poses a unique problem for science: it violates a universal assumption that the phenomena studied by science should be equally available to all observers, and no observer should have a privileged access to a phenomenon. Even though representational contents consciousness can be successfully mapped using neuroimaging techniques, specific blood-flow or electrophysiological activation patterns do not provide access to the subjective experiential qualities (see Section 4.4). Consequently, there seems to be an unbridgeable *explanatory gap* between the objective neurophysiological data and the subjective contents of consciousness: even if we are certain that the existence of consciousness is dependent on the brain, we cannot understand how brain activities cause or constitute consciousness (Levine, 1983; McGinn, 1989). Reductive analyses of consciousness, i.e., suggestions that consciousness is identical with some types of brain processes or functional descriptions, always seem to be logically consistent with the absence of phenomenal subjective experience despite the presence of these processes (Chalmers, 1996; Nagel, 1974). These intuitions have been illustrated by several famous thought-experiments (Jackson, 1986; Nagel, 1974). Nagel (1974) argued that even if objective science would acquire all physical facts about humans or other mammals, we would still miss information about their subjective point of view. For instance, even if we would know all neurophysiological and behavioural facts about a bat, including its sensory echolocation system, we would still have no idea of 'what is it like to be a bat', for example, what are its subjective experiences of flying in the complete darkness between the trees. Likewise, the same argument can extended to other conscious organisms, including humans: their subjective point of view is always left out in an objective scientific description of behaviour and neurophysiology (Nagel, 1974). Jackson (1986) argued that a neuroscientist who is congenitally colour blind but knows all objective facts about the psychophysics and physiology of colour perception would still learn something new if one day her colour vision would be cured, which seems to indicate that there might be more to consciousness than physical facts about its mechanisms.

Many of the consciousness-related research problems, such as the ability of a system to access its own internal states or the difference between wakefulness and sleep, seem to be relatively *easy*, i.e., they seem to be directly susceptible to the standard methods of cognitive neuroscience (Chalmers, 1995). Even though some of the easy problems of consciousness are not yet solved, we have a clear idea of what would be their scientific explanation: discovery and description of computational and/or neural mechanisms would solve each of these problems. Contrary to this, the problem of the material basis of conscious experience is a problem of a different type: it is a *hard problem*, which seems to resist any of the empirical methods available to the contemporary science (Chalmers, 1995). We do not have any idea of how and why subjective sensations or emotions arise from a physical basis, and yet they do.

Even worse, we cannot even imagine how this problem could be solved in terms of neurophysiological or neurochemical processes.

The *hard problem* can be tackled by a number of different philosophical theories of the mind-body relationship, and some of these theories, such as dualism or panpsychism, do not seem to have the hard problem of consciousness at all. Arguably, it applies only to materialistic theories that aim to explain subjectivity in terms of objective physical or biological processes. In Section 2.4 following, some of the most influential classical and contemporary metaphysical theories of the mind-body relationship will be presented and evaluated, with a special focus on the biological approaches to the consciousness-brain interaction.

2.4. Philosophical theories of the mind-body problem

2.4.1. *Classical solutions to the mind-body problem*

Throughout centuries of theoretical research, controversies between dualism versus monism, idealism versus realism, and rationalism versus empiricism, placed the mind and consciousness at the top of philosophical investigations (Crane & Patterson, 2000; Heinämaa et al., 2007). Dualistic approaches to the mind-body problem assume that the mind (or certain aspects of it) and the physical world are ontologically separate and cannot be reduced to each other. Proponents of *substance dualism*, most notably Descartes (1641), suggested that consciousness and the brain are different substances, which can exist independently of each other. *Property dualists* supposed the existence of one substance with two fundamentally different aspects, i.e., mentality and materiality, where mental properties do not exist in the absence of physical properties (e.g., Mill, 1843). Contrary to dualistic positions, monism assumed the existence of only one independent substance. For instance, La Mettrie (1748) defended a *materialistic* position (also called *physical monism*), arguing that consciousness has purely physical causes and there is no necessity to assume the existence of a separate 'soul-substance'. On the opposite extreme of monistic positions lied *idealism* (also called *mental monism*), which states that consciousness is the only ontologically real substance, whereas all the other material substrates are derivable from it (Berkeley, 1710), i.e., brain and other physical phenomena are real, but only as the subjective contents of consciousness. Further developments of classical solutions to the mind-body problem showed that there is no 'pure dualism' or 'pure idealism', but instead there are many different versions of them (Morton, 2010), some of which continue being considered and developed. For instance, findings in modern physics and neuroscience may inspire brain and physics-oriented refinement of property dualism (Popper & Eccles, 1977) and even idealism (Bolender, 2001).

2.4.2. *Contemporary theories: from eliminativism to panpsychism*

Contemporary ontological theories of consciousness provide a wide range of solutions of how consciousness and the brain might be related, which indicates the lack of a single widely convincing ontological theory of consciousness. For instance, *reductionism,* one of the materialistic theories of the mind-body relationship, suggests that each type of mental state or process is identical to some type of neural state or process (Lewis, 1966; Smart, 1959). According to the *type-type identity* theory, which is a version of reductionism, there is no difference between a particular neural level in the brain and consciousness. Yet, the identity relationship implies that certain neural processes and consciousness are sharing all properties, whereas conscious experiences have subjective qualitative aspects that the neural mechanisms do not seem to have. If so, consciousness cannot be identical or reducible to any of the objectively observable neural states or processes. A possible answer to this argument is provided by *eliminativism*, which states that subjective properties do not physically exist. The most fundamental is the existence of the brain and the whole body, while the subjective aspect of perception is nothing more than an epiphenomenal illusion; a misrepresentation about functioning of our brains without any causal power (Churchland, 1999; Dennett, 1978, 1991). Yet, even if one agrees that consciousness is illusion, there is something left to be explained: how the brain can produce this subjective illusion.

Not all ontologies of mind that take the physical world seriously seek to reduce or eliminate phenomenal consciousness. For instance, *embodiment* theories assume that subjective experiences depend on the physical world, but processes and entities which are necessary for consciousness are not limited to the brain: the contents of consciousness are ontologically dependant on causal relations with peripheral body as well as with external physical objects (Noë & Thompson, 2004; Thompson & Varela, 2001). The embodiment approach seems to be plausible in the case of visual perception, as one of the prerequisites of vision is external physical stimulation of retina, yet embodiment theories do not provide a satisfactory explanation of how internal subjective experiences are generated in the absence of behavioural embodied interactions with the world, such as during mental imagery or dreaming. While the embodiment approach extends physical foundations of consciousness from the purely brain-based mechanisms to the peripheral body and immediate physical stimuli, *panpsychism* goes further and proposes that consciousness may be just about everywhere. For instance, Chalmers (1996) argues that information implemented in any physical system, such as the brain, flowers or microwaves, is conscious, i.e., it is a natural law that information realized physically is phenomenally conscious (see Tononi 2001, 2012; Section 2.5.5). Several related proposals have been put forward by researchers arguing that consciousness is a property of a matter at the level of fundamental physical forces, such as those described by quantum mechanics (Bohm, 1990; Jibu & Yasue, 1995). However, physics- and information-oriented theories have difficulties in explaining why consciousness is so tightly related to certain processes in the brain, as demonstrated by numerous cognitive neuroscience studies (but see Hameroff, 2007).

Functionalism suggests that the ontology of consciousness is determined by abstract causal interactions between perceptual, cognitive and behavioural processes. In fact, functionalistic theories propose that any mental state could be defined by sensory inputs, inner informational processes and behavioural outputs (Fodor, 1975; Wright, 1973). Descriptions of such functional interactions have been successfully used in cognitive sciences to explain human rationality and decision making (Clark, 2001), which fuelled expectations that consciousness could be explained likewise (Dennett, 1978). Importantly, the abstract level of functional explanations implies that biological brains are not necessary for the generation of consciousness, as the same abstract functions and algorithms can be implemented in different physical substrates. The possibility of multiple realizations of functional interactions seems to provide theoretical grounds for building artificial intelligence and consciousness (Aleksander, 2005). Yet, while being a promising theory for identifying functional roles of consciousness, functionalism does not escape from difficulties in explaining qualitative aspects of consciousness (Block, 1980), as it remains unclear why some, but not all, functional networks are conscious. Difficulties in conceptualizing a convincing ontological theory of consciousness have even led to a position called *mysterianism*, also known as *strong emergent materialism*: even if consciousness is a material phenomenon, the human brain may simply be too limited and incapable of explaining the mind-body relationship, just as, for instance, dog brains are incapable of understanding modern physics (McGinn, 1989, 1991).

2.4.3. *Biological approaches to consciousness*

The majority of the empirical researchers of consciousness tend to follow assumptions of *biological naturalism*, which is a scientific common sense position that consciousness is a qualitative, subjective, unified and (usually) representational high-level brain function (Searle, 1992, 2007). Importantly, even though consciousness is thought to be caused by the lower level brain processes, it also seems to be irreducible to them and having its own causal efficacy to influence cognition and behaviour (Searle, 2007). Consistently with these intuitions, *biological realism* assumes that phenomenal consciousness is a real biological phenomenon that resides within the confines of the brain and cannot be reduced to the fundamental laws of physics (Revonsuo, 2006). Given that being real implies having its own causal powers (Kim, 1992), consciousness is assumed to be subordinated to causal interactions with other neural processes in the brain and, through them, with the rest of the body and the physical world. Methodologically, biological realism proposes that subjective experiences as biologically real phenomena should be studied by the sciences of biology. In particular, material basis of consciousness should be studied within the spatial and temporal scales that are common for neurosciences. Further, biological realism assumes that we are not cognitively closed to the understanding of consciousness, but instead biological sciences, especially cognitive neuroscience, are (or will be) able to explain it (Revonsuo, 2006). Thus, metaphysically, biological realism represents the *weak emergent materialism*, which predicts that the complete understanding of the brain will explain how consciousness emerges from the brain processes (Revonsuo, 2010). Contrary to this, the *strong emergent materialism* assumes that the neural basis of consciousness will remain unresolved even when all facts about the human brain will become known to the scientific community (see Section 2.4.2).

While explanation in physics typically involves description of universal natural laws through which an explanandum, i.e., the target of explanation, can be reduced to physical processes at the smaller spatial and temporal scales, explanation in biological sciences involves description of multilevel mechanisms whose causal interactions are too complex to be described by universal laws (Bechtel & Richardson, 1993; Craver, 2007; Craver & Darden, 2001). Instead, biologists, including cognitive neuroscientists, develop constitutive, contextual and etiological explanations of their explanatory target (Revonsuo, 2006). Constitutive explanations reveal the lower levels of a phenomenon under investigation, for example, neuronal long-term potentiation can be described as an emergent outcome of the lower-level NMDA receptor activation (Craver & Darden, 2001). Contextual explanations point to the functional roles of explanandum in interaction with the higher levels of biological organization. Etiological explanations describe biological processes that are capable of modulating the explanandum, but cannot constitute it, such as abnormal developmental pathways. Consciousness is assumed to reside in the largely unknown phenomenal level of organization in the brain (Revonsuo, 2006), yet it is expected that descriptions of interactions between the cognitive, phenomenal and neural level of organization will eventually solve the mind-body problem (Bechtel & Mundale, 1999).

However, despite continuous development of a biological research programme during the previous decades and its relative success in identifying some neural correlates of consciousness (see Section 2.5), the hard problem of phenomenal consciousness (see Section 2.3) remains unsolved. Thus, even though cognitive neuroscience and neuropsychology already yielded a number of fascinating discoveries and neurocognitive theories (see Section 2.5), it remains possible that some other approaches to consciousness than the one defended by biological realism might prove to be more accurate. For instance, it might turn out that phenomenal consciousness emerges as a product of multi-level functional interactions between biological entities and processes, and that these interactions can be replicated in artificially designed systems. This would contradict the assumptions of biological naturalism and realism, which are regarded as an alternative to functionalism (Revonsuo, 2006; Searle, 1984). Likewise, information integration and differentiation theory of consciousness (Tononi, 2012; see Section 2.5.5) may loosen its ties with neuroscience, if consciousness-generating informational complexity would be detected or designed in non-biological systems. As long as the uncertainty over the neural basis of consciousness continues, it is suggested in this doctoral thesis to commit to a less ambitious but more open and pragmatic approach to consciousness than the one defended by the biological realism, at the same time following the main methodological suggestions of biological realism. This methodological approach will be called as *neurobiological pragmatism*.

In the philosophy of pragmatism, scientific theories are regarded as instruments that help to facilitate empirical research and increase the understanding of explanandum (James, 1907). Theories are evaluated depending on the success of their application; when scientific progress diminishes, the existing theories and methodologies are replaced by new instruments that are more likely to facilitate further development of science. Given that currently neuroscience provides the most efficient tools for the advancement of the science of consciousness, *neurobiological pragmatism* would call for directing financial and human resources to the cognitive neuroscience studies of consciousness. Following methodologies outlined by biological realism (Revonsuo, 2006, see also Craver, 2007), neurobiological pragmatism would seek for a multilevel explanation of neural mechanisms of consciousness. However, biological realism assumes that a complete understanding of the neurobiology of brain would naturally lead to the explanation of consciousness (Revonsuo 2006, 2010), which excludes a possibility that consciousness might be realized as a non-biological phenomenon. Contrary to this, *neurobiological pragmatism* would propose that consciousness is most likely to be explained by neurosciences, however, biological explanations may not be sufficient for solving the hard problem of consciousness, and neurobiological pragmatism may eventually be replaced by 'informational pragmatism', 'physical pragmatism', or some other set of methodologies. Nevertheless, steps towards exclusively non-biological methodologies should be carried out only when the potential of neurobiological paradigms is sufficiently exploited. More likely, instead of abandoning biological approach, it may merge in future with other approaches, leading to a 'multidisciplinary pragmatism'. Notably, neurosciences are already receiving substantial contributions from other sciences. Even contemporary analyses of fMRI, EEG or magnetoencephalography (MEG) correlates of subjective experiences, as well as computational neuroscience of consciousness, are hardly limited to classical biological methods, but instead they require collaboration between neuroscience, psychology, physics, signal processing and mathematics.

Regarding metaphysical commitment, neurobiological pragmatism would remain open to different possibilities of the mind-body relationship, known here as a *weak ontological pluralism*. In a strong reading of ontological pluralism, it suggests that there are different kinds or modes of being, which allows co-existence between different ontological assumptions, as proposed in logic (Turner, 2010, 2012), but also discussed in the context of epistemology and metaphysics (Northoff, 2004). In the weak reading, ontological pluralism would suggest that different ontological assumptions may co-exist, but also that ontological monism may be more accurate. For instance, a biological approach may eventually require its extension towards physical accounts of consciousness, panpsychism, property dualism or dual aspect monism, but also a weak emergent materialism may turn out to be true. Until science and philosophy provide conclusive evidence and arguments, it is too early and premature to commit to a single ontology of consciousness, as this may hinder other more accurate, yet currently neglected possibilities. Importantly, none of the discussed philosophical theories of the mind-body relationship neglects the importance of biological research, as even in substance dualism non-material entities are thought to be able to cause changes in the brain (Descartes, 1641), which subsequently can be studied empirically. Thus, successful implementation of the methodology of biological realism may lead to, but currently does not require, the acceptance of emergent materialism and is compatible with metaphysical indeterminacy. While it is feasible to focus on the neurobiology of consciousness, we do not know yet where we will end up in trying to explain the hard problem of consciousness. Some of the currently most influential neurocognitive theories of consciousness are detailed in the following Section 2.5.

2.5. Neurocognitive theories of consciousness

2.5.1. *Historical sources of empirical consciousness research*

Beginnings of the modern empirical research of consciousness can be traced back to the behavioural psychophysics experiments conducted by Weber (1834) and Fechner (1860), who studied the relationship between the physical intensity of various stimuli and the threshold of 'just noticeable difference' in subjective sensation of these stimuli (for review, see Frith & Rees, 2007). Donders (1868) developed an experimental paradigm to compare simple and two-choice reaction time tasks, which allowed differentiating mental and motor processes preceding motor responses. Duration of mental events was further investigated, although more introspectively, by Wundt (1862), who established the first psychology laboratory in Leipzig in 1879. The first empirical studies of dream content were also carried out in the second half of the nineteenth century (for review, see Noreika & Windt, 2008). For instance, Maury (1861) investigated the influence of external stimuli on dreams, whereas Calkins (1893) proposed a statistical analysis of dream reports. Wundt's student Titchener (1902) formalized introspection techniques and analysed consciousness by systematically breaking it down into elementary feelings and sensations, which led to the structuralistic theory of mind. James (1890) took a different approach and instead of searching for the atoms of mind emphasized the continuity of conscious experiences that flow as a single stream of mental states (see Section 2.2). Despite important theoretical advances and development of new experimental paradigms, most of the nineteenth century consciousness researchers relied on introspection, which was critically rejected by Watson (1913) and other behaviourists who argued that the only scientifically rigorous method to study the human mind is a search for systematic relationships between external stimuli and behavioural responses.

The detailed critique of the methodology of introspectionism was soon accepted as the general denial of the existence of consciousness itself. During domination of behaviourism in the first half of the twentieth century, the topic of consciousness was removed from most of the scientifically oriented textbooks or university programmes of psychology. Even though alternative approaches to the study of mind did not completely cease, for example, research of principles of visual grouping led to the description of Gestalt laws of vision (Wertheimer, 1923), they were marginalized for several decades until the development of information theory (Shannon & Weaver, 1949) enabled the mathematical account of mental processes and triggered the boost of cognitive psychology experiments (for review, see Frith & Rees, 2007). Nevertheless, it took another thirty to forty years until quantitatively oriented psychology and neuroscience returned to the topic of consciousness (Baars, 1988; Crick, 1994). Notable exceptions in the neglect of subjective experiences were split-brain studies in the 1960s and 1970s (for review, see Gazzaniga, 2005) and empirical research of psychophysical mechanisms and subjective contents of dreaming, which flourished between 1953 and 1993 (for review, see Foulkes, 1996).

2.5.2. *Global workspace theory of consciousness*

The return of empirical sciences to the problem of consciousness was largely inspired by Baars (1988, 1997, 2002), who developed a global workspace theory of consciousness that seeks to explain consciousness through its functional interactions with other cognitive processes and functions, including attention, working memory, action control, problem-solving, and language. In particular, Baars (2002) proposed the 'conscious access hypothesis', according to which the main function of consciousness is an integration, coordination and distribution of different brain processes that otherwise would remain isolated, limited, and unconscious. Consciousness can be metaphorically described as a spotlight (i.e., the focus of attention) on a theatre stage, called global workspace (i.e., working memory), which is controlled by the theatre director (i.e., executive Self) (Baars, 2002). From a vast number of the parallel and unconscious information processes, consciousness identifies the most relevant process or representation, and distributes it widely across other cognitive functions. In the global access networks, unconscious resources, such as memories or automatisms, may become the contents of the conscious spotlight in the working memory, and subsequently may modulate cognitive contexts, such as expectation and intentions of Self (Baars, 2007). The spotlight of attention may switch from modality to modality at a rate of about 100 ms, which is considered sufficient to produce the sense of phenomenal unity across different contents of consciousness (Baars, 1998). Depending on the contextual demands, the duration of particular contents of consciousness may also be extended by re-initializing loops between unconscious resources, working memory and contexts, which, for instance, would be needed for episodic and explicit learning or voluntary control of motor activity.

Global workspace theory and models were further developed by Franklin (2003), who integrated it within a computation model of cognition, and Dehaene and colleagues who investigated neurophysiological mechanisms of the global distribution of conscious information in the brain (Dehaene et al., 2001; Dehaene & Changeux, 2011). For instance, it was demonstrated that unconsciously presented backward-masked visual words evoke localised activation of the extrastriate, fusiform and precentral areas, whereas conscious presentation of words in addition activate broad frontal and parietal networks (Dehaene et al., 2001), arguably reflecting wide access and broadcasting of conscious information (Baars, 2007). At the electrophysiological level of description, conscious access and global broadcasting seem to take place through the long-distance synchronization of the beta and gamma frequencies (Dehaene & Changeux, 2011). Yet, despite immense progress in the understanding of functions and neural mechanisms of conscious access, the global workspace theory of consciousness does not seem to offer a satisfactory account of the phenomenal consciousness. In fact, Baars (2007) argues that the typical consciousness-related questions, such as the status of qualia and the hard problem of subjectivity (see Section 2.3) do not apply to the global workspace theory of consciousness. This is simply because the global workspace theory is a theory of access consciousness, and perceptual processes outside of the cognitive machinery of global broadcasting, i.e., the contents of pure phenomenal consciousness, are regarded as pre-conscious at best (Dehaene et al., 2006). Such an approach may be successful in the identification of the cognitive interactions and functions of consciousness. However, it does not provide a satisfactory explanation of the neural mechanisms of subjective experience, as it assumes that there is no phenomenal consciousness independent of or prior to access consciousness. Phenomenal consciousness as such becomes largely eliminated from the theory.

2.5.3. *Micro-consciousness vs. macro-consciousness*

While Baars (1997) and Dehaene et al. (2006) argued for the global workspace theory of consciousness, Zeki (2003, 2007) rejected the classical notion of the unity of consciousness (see Section 2.2.) and proposed that consciousness exists in the form of many autonomous units called ‘micro-consciousnesses’. Neurological observations and measurements of asynchrony of visual perception suggest that micro-consciousness units are distributed in both space and time (Zeki, 2007; Zeki & Bartels, 1999; Zeki & ffytche, 1998). For instance, lesions in the visual color area V4 produce achromatopsia, but do not affect motion awareness, whereas lesions in the visual motion area V5 produce akinetopsia, but do not deteriorate colour awareness. Neurological cases seem to suggest that an intact V5 is necessary and sufficient for the awareness of motion, even when primary visual cortex V1 is lesioned (Zeki & ffytche, 1998). Further, conscious perception, as opposed to unconscious information processing, may not involve any additional cortical region but instead it may differ by the increased activation level of the same cortical areas, and in principle any anatomical region of cortex could produce its own micro-consciousness (Moutoussis & Zeki, 2002). Regarding temporal asynchrony of visual micro-consciousness units, there is evidence showing that the earliest to reach the required level of activation is micro-consciousness of location, followed by micro-consciousnesses of colour, orientation and then of motion (Bartels & Zeki, 2004; Moutoussis, 2012).

Zeki (2003) distinguished three levels of consciousness: *micro-consciousness* as subjective perception of basic phenomenal properties; *macro-consciousness*, i.e., the totality of micro-consciousness units, as subjective perception of meaningful objects; and *unified consciousness* as subjective awareness of Self. In this framework, the unity and binding are not treated as fundamental properties of phenomenal consciousness. Instead, temporary jumping activation of different areas in cortex is assumed to be sufficient for the awareness of objects and scenes at the macro-consciousness level of perceptual organization. Yet, even though Zeki's research programme shows that isolated but conscious neuronal units may exist in the cortex, the suggested account of the disunity of consciousness is not consistent with our phenomenology, as single objects as well as more complex sceneries appear to us in a unified form rather than as a stream of temporary and spatially disintegrated features. Instead, the findings of Zeki et al. seem to point to the lower representational or information processing levels of consciousness.

2.5.4. *Recurrent processing as the neural basis of consciousness*

Lamme (2006) proposed that the generation of phenomenal consciousness depends on the recurrent information processing between different modules across hierarchical neuronal networks. For instance, the feedforward information sweep across regions V1, V2, V4, TE of the visual ventral stream is not sufficient for the generation of conscious perception, although it may contribute to visually guided actions. Contrary to this, recurrent processing between V1, V2, V4, TE and between the ventral stream and fronto-parietal networks will lead to reportable conscious perception. Moreover, Lamme (2006) argued that recurrent processing within the ventral stream is capable of generating conscious perception even when the ventral stream does not interact with the fronto-parietal accessibility networks. If so, the contents of visual awareness cannot be equated with the attentional focus and working memory (as opposed to Baars, 2002, 2007, see Section 2.5.2), but instead visual awareness and attention are doubly dissociable (Lamme, 2003, 2004).

Hypothesized independence of phenomenal consciousness from the access and reportability became one of the main controversies in consciousness research (e.g., Block, 2011; Kouider et al., 2012). In particular, given that the presence of isolated micro-consciousness-type of processes (Zeki, 2003, 2007, see Section 2.5.3) cannot be proved directly as they are unreportable (see Section 4.1), there can be only indirect and thus questionable evidence of subjective experiences that are not available for access consciousness. Furthermore, it remains unclear why recurrent processing is necessary for the emergence of phenomenal consciousness. Possibly, the complexity of neuronal processing required for the generation of conscious experience cannot not be achieved instantly and requires temporally extended information processing, which may also point to the neural mechanisms of specious present (see Section 2.2.1).

2.5.5. *Information integration theory of consciousness*

Instead of selecting specific brain regions or electric frequency bands, information integration theory of consciousness, developed by Tononi (2001, 2004, 2010, 2012), equates human conscious experience with integrated information in the brain. Each conscious experience rules out an extraordinarily large number of alternative perceptual possibilities, making it highly informative (Tononi, 2007). Further, information in conscious systems is exceedingly well integrated between the elements constituting such systems, and the state of each element causally depends on the state of other elements. Consequently, phenomenal contents of a conscious state cannot be divided into phenomenal contents of its elements, as such a disintegration of information would lead to the loss of consciousness. Given that the presence of consciousness can be equated with the presence of integrated information, empirically feasible measures of such information can be developed to detect consciousness. Tononi and Sporns (2003) detailed some preliminary analytic tools to assess Φ – the capacity of a system to integrate information. Effective information between any two given subsets of a system can be assessed by injecting maximum possible entropy to one of the subsets and measuring complexity of responses of another subset. By comparing effective connectivity between all possible subsets of a system, one can identify if complexes of elements exist that maintain integrated information Φ that is lost if some of the elements become isolated from the complex (Tononi, 2008).

Tononi (2007) argued that information integration theory is consistent with phenomenological observations of informativeness and unity of consciousness, as well as psychophysical studies showing that at least 100–200 ms are required for the emergence of consciousness (Bachmann, 2000), which, given the neuronal processing speed, is roughly the time required for information to be integrated in the highly connected neuronal networks in the human brain. Generation of consciousness may depend on the high-level organization of thalamocortical networks, which seem to support both functional specialization (Zeki, 1993) and functional integration (Engel et al., 2001). By contrast, as predicted by the information integration theory, cerebellar networks consisting of an even higher number of neurons than cerebral cortex but lacking associative connections (Bower, 2002), do not seem to be directly involved in the generation of conscious experience. Likewise, consciousness is absent when cortical networks lose effective connectively and presumably the capacity to integrate information during slow wave sleep or anaesthesia (Massimini et al., 2012). However, even though information integration measures are already used in empirical studies of consciousness (e.g., Casali et al., 2013; Lee et al., 2009), it remains unclear how to assess the minimal degree of information integration required for consciousness to emerge. It is also unclear whether any integrated information, including artificially designed systems, would be conscious. Tononi (2007) seems to support the later conclusion, somewhat turning away from biological realism towards informational panpsychism (Chalmers, 1995) (see Sections 2.4.2 and 2.4.3).

After describing some of the most important concepts used in consciousness research, the fundamental properties of consciousness, the hard problem of consciousness-brain interaction, and how this problem is approached in philosophy and cognitive neuroscience, Section 3 following will focus on definitions and different types of ASCs.

3. ALTERED STATES OF CONSCIOUSNESS

The stream of consciousness does not always flow continuously, and every now and then we may experience a significant alteration of consciousness, for example, when we meditate, or – in a less fortunate case – when we get sedated or anaesthetized due to a medical condition. Some of these alterations are subtle and hardly noticeable, whereas others are very obvious, such as a change of subjective experiences in the transition from waking to sleep, yielding hypnagogic hallucinations (Ohayon et al., 1996). What happens to the phenomenal contents of consciousness in these states? Do they provide unique experiences that are not available in the normal waking state of consciousness? How can we assess the contents of consciousness of another person undergoing an alteration of consciousness, for example, a hallucinating patient? Studying such alterations is important not only for the social or fundamental understanding of human consciousness, but also for their clinical relevance, as unusual subjective experiences might be psychologically disturbing and distressing (Delespaul et al., 2002).

3.1. Definitions and classifications

During the last decades of research, a large number of diverse phenomena have been linked to or called *altered states of consciousness* (ASCs), including coma and vegetative state, daydreaming, drowsiness, epilepsy, extreme environmental conditions, hypnagogic states, hypnosis, meditation, near-death experiences, psychotic disorders, relaxation, respiratory manoeuvres, rhythm-induced trance, sensory deprivation, homogenization or overload, sexual activity and orgasm, sleep and dreaming, starvation and diet (Vaitl et al., 2005). This and similar lists of ASCs illustrate the complexity of the theoretical problem of trying to find unifying principles of all ASCs. Most of the definitions of ASCs focus on changes in subjective experiences and a subsequent reflection over these changes. For instance, Farthing (1992) defines an ASC as ‘a temporary change in the overall pattern of subjective experience, such that the individual believes that his or her mental functioning is distinctly different from certain general norms for his or her normal waking state of consciousness’ (p. 205) (see also Ludwig, 1966; Tart, 1972). The main problem with this group of definitions is that ‘altered’ is circularly defined as ‘a change’ and there are no formal criteria given to operationalize what degree of a change is needed for an ASC to be identified (Revonsuo et al., 2009). The requirement for self-awareness of a significant change of phenomenal consciousness does not hold for some of the classical ASCs, for example, a dreaming or a psychotic individual does not always realize that he or she is in an ASC.

Instead of focusing on changes in phenomenal contents of consciousness, an alternative representational definition of ASC was recently developed by Revonsuo et al. (2009) who suggested that an ASC is ‘a state of the mechanisms of representation in the brain resulting in a global misrepresentational organization of the overall contents of consciousness at some moment in relation to the surrounding (‘‘world’’) context (in which they occur)’ (p. 195–196). This definition of an ASC focuses on changes in the preconscious or non-conscious background representational mechanisms of consciousness, which are more easily available for an objective verification than internal subjective experiences. However, similarly to the phenomenal definition of an ASC, the representational definition does not seem to hold for all ASCs. For instance, neutral hypnosis, which has been suggested to be a powerful contrast condition for studying neural mechanisms of hypnosis (Kallio & Revonsuo, 2003), does not seem to involve any observable representational changes. Furthermore, conceptually, misrepresentation cannot be attributed to an object or a process that does not aim to represent. For example, a drawing of Barack Obama will probably misrepresent the current President of the United States of America, however it is not meaningful to attribute a property of misrepresentation of George Bush to the same drawing as it was not intended to represent him. Likewise, the contents of dreaming during sleep may not misrepresent external physical environment simply because they are not aimed at representing it.

Notably, it seems to be extremely difficult to grasp a common core of all ASCs in a single definition, as they might be both very similar and fundamentally different from each other depending on the comparison axis (Móró, 2010). Historically, naming different phenomena as ASCs was not theory-driven, but instead led by a general increased interest in the research of dreaming, meditation and LSD-induced alterations of consciousness in 1950s and 1960s (Metzner, 2010). The first operational definitions of an ASC were proposed when the concept of ASCs was already widely used (Krippner, 1972; Ludwig, 1966; Tart, 1972). A decade ago, instead of suggesting a single unifying definition of an ASC, a consortium of fifteen researchers working in the field took an alternative approach and suggested a unifying four-dimensional descriptive system under which all classical ASCs can be mapped (Vaitl et al., 2005). According to this proposal, consciousness can be altered across four dimensions: (1) activation or readiness to respond (aroused vs. relaxed); (2) awareness span or availability of experiences for attentional processing (wide vs. narrow); (3) self-awareness (present vs. absent); and (4) sensory dynamics (increased vs. decreased). For instance, typical dreaming can be characterized by relaxed activation, wide awareness span, present self-awareness and increased sensory dynamics (Vaitl et al., 2005).

Furthermore, Vaitl et al. (2005) classified ASCs according to the methods of their induction, namely: (1) spontaneously occurring; (2) physically and physiologically induced; (3) psychologically induced; and (4) disease induced. This classification proved useful as it helps to find commonalities within a particular class of ASCs, for example, not only dreaming, but most of the spontaneously occurring ASCs can be characterized by relaxed activation, narrow awareness span, present self-awareness and increased sensory dynamics (Vaitl et al., 2005). However, the consortium members excluded pharmacologically induced alterations of consciousness, which form one of the largest classification groups of ASCs, including those induced by recreational drugs, psychoactive medical drugs, anaesthetic agents, and legal stimulants, such as caffeine and alcohol (Meyer & Quenzer, 2005). Furthermore, physically, physiologically and psychologically induced ASCs may not be that different, as they all share a cognitive decision and effort to reach an ASC. In this doctoral thesis, four categories of ASCs will be distinguished, refining the earlier classification by Vaitl et al. (2005): (1) naturally occurring; (2) cognitively induced; (3) pharmacologically induced; and (4) pathological alterations of consciousness. The concepts of an ASC and *an alteration of consciousness* will be used interchangeably as synonyms to refer to the historically named ASCs (Farthing, 1992). No priority will be given to either phenomenal or representational definitions of an ASC, as none of them seem to include all relevant ASCs. Likewise, no single state will be regarded as the main baseline state for a contrast with an ASC. Even though a state of relaxed wakefulness may seem to be the most suitable baseline for an ASC (see Section 2.1.5), varying experimental paradigms of different alterations of consciousness may require choosing different states for a contrast with a particular ASC (see Section 4.1).

3.2. Dreaming: a naturally occurring alteration of consciousness

Natural alterations of consciousness take place in healthy individuals when unexpected or unusual intense perceptual, cognitive or emotional experiences occur spontaneously without any effort and, typically, without external physical stimulation. The most paradigmatic natural ASCs are nocturnal dreaming and a large group of other sleep-related alterations, including hypnogogic and hypnopompic hallucinations, sleep mentation, nightmares, lucid dreams, sleep paralysis and night terrors (Farthing, 1992; Hobson, 2001; Vaitl et al., 2005). *Dreaming* can be defined as the presence of 'complex, multimodal, dynamic and progressive conscious experiences during sleep that are organized in the form of sensory-perceptual world or a world simulation' (Revonsuo, 2009, p. 295). The definition emphasizes the spatial integration of multimodal perceptual experiences into a coherent world model and the temporal development of these experiences. However, not all perceptual experiences are dynamic during sleep, and minimal forms of dreaming exist with spatially complex but temporally static contents of consciousness (*Study II*, see Section 6.3), demonstrating an alteration of fundamental temporal properties of consciousness (Noreika et al., 2010c). Other perceptually relatively simple sleep-related ASCs are *hypnagogic and hypnopompic hallucinations*: sensory experiences occurring at the transition from wake to sleep, or from sleep to wake (Ohayon et al., 1996). While due to the suppression of reflective consciousness we are not typically aware of the fact we are dreaming, reflective consciousness is present during *lucid dreaming* in which the dreamer knows that he or she is dreaming (Farthing, 1992). Different types of dream lucidity will be investigated in *Study VI* (see Section 6.7).

Despite a close phenomenological resemblance of dreaming and waking experiences (Revonsuo, 2006), they are extremely different when it comes to their immediate sources: dream experiences are internally simulated, whereas waking experiences are largely driven by the prediction of external stimuli (Hobson & Friston, 2012). In addition, the dreaming mind has a number of cognitive deficiencies, such as the lack of metacognition (Windt & Metzinger, 2007), as well as unusually high incidence of negative emotions when compared to the waking life (Nielsen et al., 1991). Perhaps the most striking aspect of dreaming is the frequent bizarreness of its phenomenal contents (Hobson, 1988). *Bizarreness* can be defined as 'places, objects, persons, and other dream contents that deviate in peculiar ways from their counterparts in waking life, or show unusual combinations of phenomenal features' (Revonsuo, 2006, p. 240). Three different types of dream bizarreness are often distinguished: incongruity, uncertainty, and discontinuity (Hobson, 1988; Revonsuo & Salmivalli, 1995; see also *Study III*, Section 6.4). *Incongruity* refers to the mismatching features of dream contents, *uncertainty* points to the explicit vagueness of dream contents, whereas *discontinuity* refers to the abrupt change of identity, time, and place of other phenomenal contents of dreaming (Hobson, 1988). Different types of bizarreness are not uniformly distributed across different contents of dreaming, but instead they show a pattern of bizarreness-clustering, for example, the most incongruous are language and cognition-related dream contents, whereas the least incongruous is the dream Self (Revonsuo & Salmivalli, 1995). Revonsuo and Tarkko (2002) argued that dream bizarreness is a result of different types of binding errors occurring during sleep, indicating a breakdown of the fundamental properties of consciousness (see Section 2.2) and providing an important database for studying the unity of consciousness (Revonsuo, 1995b).

Given the broad complexity of dream experiences, a very large number of dream content analysis scales have been developed (Winget & Kramer, 1979), measuring selected aspects of phenomenal contents of consciousness, the most notable of which is the *Hall and Van de Castle Scale for the Content Analysis of Dreams* (Hall & Van de Castle, 1966). In addition to the content analyses of dream reports (for more details, see Section 4.2), an increasing number of studies aim to bridge from the dream phenomenology to the underlying sleep neurophysiology (Nir & Tononi, 2010). While the early attempt to establish a necessary and sufficient link between dreaming and physiology of REM sleep (Aserinsky & Kleitman, 1953) have largely failed, as up to 40% of NREM sleep awakenings yield dream reports (Nielsen, 2000), some of the recent studies have aimed to identify the neural mechanisms of particular contents of dreaming. For instance, analysis of diffusion tensor imaging has recently linked the trait of high dream bizarreness with the relatively low volume of left amygdala, whose decreased microstructural integrity was also associated with the lower emotional load of dream reports (De Gennaro et al., 2011). In another recent study, dream lucidity was found to be associated with the specific high-frequency EEG patterns in the frontal sensors (Voss et al., 2009). For a proposal of a novel brain stimulation paradigm to study neural mechanisms of lucid dreaming, see *Study VI* (Section 6.7).

3.3. Hypnosis: a cognitively induced alteration of consciousness

ASCs may occur in response to deliberate cognitive and/or behavioural efforts, when a repetitive action, thought or attention concentration leads to alterations of subjective experiences and the underlying representational and neural processes. The most known *cognitively induced alterations of consciousness* are meditation and hypnosis, the first of which can be achieved by meditators themselves, while the second typically requires an interaction between a hypnotist and a hypnosis participant. Typically, a hypnosis session consists of the induction and suggestion phases (Farthing, 1992). During induction, a hypnotist guides an individual participant or a group of participants through a set of relaxation commands. Afterwards, when a participant becomes deeply relaxed, a hypnotist may give ideomotor, response-inhibition and/or cognitive suggestions (Hilgard, 1965), the choice of which will depend on a particular clinical or experimental purpose of the hypnosis session. Receptivity of hypnotic suggestions is highly variable across individuals, and various hypnotizability scales, such as the *Stanford Hypnotic Susceptibility Scale: Form C* (Weitzenhoffer & Hilgard, 1962), are used to identify individuals with low, medium or high hypnotic susceptibility. Distinctions between hypnotizability categories are based on the count of individual's positive responses to the standardized suggestions, such as 'you are now beginning to have a sour taste in your mouth' (Weitzenhoffer & Hilgard, 1962).

Interestingly, hypnosis is a rather passive state of the mind and if left unguided by a hypnotist, individuals under hypnosis would not necessarily detect any obvious alterations of consciousness. Yet, when suggested, highly susceptible individuals may experience intense perceptual changes, such as positive and negative visual hallucinations (Spiegel, 2003), or even more complex hypnotic dreams (Raz et al., 2009). Regarding cognitive changes under hypnosis, a well-replicated finding is a facilitation of selective attention (Raz, 2005), which may even lead to the cessation of the Stroop effect (Raz et al., 2002). In a state of neutral hypnosis, i.e., when no specific post-induction suggestions are given, a common finding is an underestimation of time (Naish, 2007), suggesting that hypnosis distorts temporal processing of the brain/mind.

Hypnosis itself can be defined procedurally, i.e., by referring to the hypnotic techniques and situational conditions controlled by the hypnotist, or phenomenologically, i.e., by pointing out cognitive and perceptual alterations experienced under hypnosis. Following the procedural approach, the Division of Psychological Hypnosis of the American Psychological Association defines hypnosis as a procedure during which 'one person (the subject) is guided by another (the hypnotist) to respond to suggestions for changes in subjective experience, alterations in perception, sensation, emotion, thought or behavior' (Green et al., 2005, p. 262). Notably, such procedural definitions do not require an alteration of consciousness to occur, but instead a very specific suggestive social interaction itself is regarded as sufficient evidence for the presence of hypnosis. As an alternative to the procedural definitions that largely ignore the subjective experiences of a hypnotized participant, phenomenological definitions emphasize 'the hypnotic state or changes in the subject's consciousness and scope of attention caused by suggestions given by another person' (Revonsuo, 2009, p. 297). According to phenomenological definitions, application of hypnotic induction and suggestions without concurrent changes in consciousness would indicate the failure rather than the presence of hypnosis. Different emphases of procedural and phenomenological definitions are not minor conceptual disagreements between hypnosis researchers, but instead they stem from the major 'state vs. non-state' controversy regarding the ontological status of hypnosis. So called *non-state socio-cognitive theories of hypnosis* argue that hypnosis is a special type of social interaction between two people, one of whom obeys and follows suggestions and commands given by another person: despite a seemingly odd behaviour, hypnotized individuals do not undergo any substantial alterations of consciousness, but instead their behaviour and cognition can be explained by standard psychological principles of compliance to the social and contextual demands, expectation fulfillment, cognitive dissociation and mental imagery (Kirsch & Lynn, 1998; Spanos & Coe, 1992; Wagstaff, 1981). By contrast, proponents of the *state theories of hypnosis* argue that hypnotized individuals undergo alterations of the mind and brain, which cannot be reduced to typical flexibility of the mental and neural functions (Gruzelier, 1998, 2005). For instance, hypnotic suggestion to perceive colours in a gray-scale stimulus is followed by subjective colour reports as well as increase of the neural activation in the extrastriate visual cortices (Kosslyn et al., 2000; Mazzoni et al., 2009; but see Mazzoni et al., 2013).

To reconcile solid evidence in support of both state and non-state theories of hypnosis, Kallio and Revonsuo (2003, 2005) proposed that two different phenomena are conflated under the same term of hypnosis. While most of the hypnotic occurrences, especially those observed in low and medium hypnotic susceptibility groups, can be explained by reference to the typical socio-cognitive processes, a genuine hypnotic ASC may take place in highly susceptible individuals. Arguably, hypnotic state occurs only in so called hypnotic virtuosos, who show all classical features of hypnotic trance and do not require prolonged hypnotic induction to reach it. If so, case studies of such individuals may be the most sensitive research program aiming to reveal the neurocognitive mechanisms of hypnotic ASC (Kallio & Revonsuo, 2003). Following this programmatic suggestion, an extensive research of eye movements of a hypnotic virtuoso T.S.-H. recently showed that 'trance stare', a classical feature of deep hypnosis, is associated with large changes in the optokinetic and pupillary reflexes and saccade programming, which cannot be imitated voluntarily (Kallio et al., 2011), supporting the state theory of hypnosis. Temporal processing in T.S.-H. will be investigated in *Study VII* (see Section 6.8).

3.4. Sedation: a pharmacologically induced alteration of consciousness

Pharmacologically induced alterations of consciousness occur in response to the intake of psychoactive substances, the most common of which are caffeine, nicotine, and alcohol. Caffeine is known to trigger energetic arousal (Smit & Rogers, 2000), whereas nicotine tends to have a tranquilizing effect (Gilbert, 1979). High doses of alcohol may induce cognitive and perceptual alterations, such as a decline of logical reasoning (Williamson et al., 2001) or reduced sensitivity in recognizing social cues of sexual interest (Farris et al., 2010). Much more complex and intense perceptual alterations occur in response to hallucinogens, such as LSD, psilocybin, mescaline or salvia divinorum, when they are used with open expectations ('mental set') in the appropriate environment ('setting') (Faillace & Szara, 1968). For instance, unusual visual experiences, such as visual trails – a series of afterimages following a moving object (Dubois & VanRullen, 2011) – may occur after the LSD intake, whereas salvia divinorum often induces the experience of derealisation, i.e., sensation of entering another reality (González et al., 2006). LSD-induced modulation of time perception, which is another common pharmacological alteration of the contents of consciousness, will be reviewed in *Study VIII* (see Section 6.9).

One of the most extreme pharmacological disruptions of the stream of consciousness occurs under the effect of general anaesthetic when an anaesthetized patient loses awareness (Alkire et al., 2008; Mashour, 2010). *General anaesthesia* can be defined either by its clinical effects or by the clinical procedures, in particular by its induction and maintenance techniques (Urban & Bleckwenn, 2002). Interestingly, a parallel can be drawn between different types of definitions of general anaesthesia and hypnosis. Both of these ASCs can be defined either by reference to their procedures or by reference to the cognitive and behavioural state of an individual under effect. Typically, definition by the clinical effects regards immobility, analgesia, unconsciousness, and amnesia as the key features of general anaesthesia (Antognini & Carstens, 2002; Heinke & Schwarzbauer, 2002; Urban & Bleckwenn, 2002). Antognini and Carstens (2002) described a gradual model of general anaesthesia in which different clinical effects are achieved at different time points during administration of the increasing anaesthetic dosage. A relatively low anaesthetic dosage supresses recall of intraoperative experiences, a higher concentration induces unconsciousness, and further increase in the dosage leads to the complete immobility.

Rather shockingly, administration of anaesthetic agents does not always result in the complete loss of subjective experiences, leading to various anaesthetic-induced alterations of consciousness. Most notably, *intraoperative anaesthesia awareness* occurs when a patient under general anaesthesia maintains or regains awareness of being operated on (Bergman et al., 2002; Mashour et al., 2012; Sebel et al., 2004). Somewhat relieving is a finding that many of the anaesthesia awareness occurrences do not involve full consciousness. Instead, only some aspects of perception or cognition are typically regained, such as hearing talking throughout the procedure or feeling intubation (Bergman et al., 2002). Likewise, even though most of awareness patients experience anxiety, sensation of pain does not always take place (Lennmarken et al., 2002). While anaesthesia awareness is a relatively rare phenomenon estimated to occur in about 0.1% of general anaesthesia cases (Mashour et al., 2012; Sebel et al., 2004), a much more common anaesthetic-induced alteration of consciousness is anaesthesia dreaming, with incidence ranging from 4% (Leslie et al. 2005) to 53% (Errando et al., 2008) of patients undergoing general anaesthesia. *Anaesthesia dreaming* is often defined as 'any experience that a patient is able to recall postoperatively that he or she thinks is dreaming and which he or she thinks occurred between the induction of anesthesia and the first moment of consciousness after anesthesia' (Leslie, 2010, p. 75). While being sufficient in the clinical context, the reliance of this definition on the explicit recall of a dream excludes a scientifically interesting possibility that unrecalled subjective experiences may exist during general anaesthesia. Arguably, most of the anaesthesia-related alterations of consciousness occur at the relatively low dosage of anaesthetic agents in a state of *sedation*, in which the use of medical agents leads to the reduced level of consciousness (Morita et al., 2002), but the individual still maintains a capacity of residual consciousness. Complexity of subjective experiences in a state of anaesthetic-induced sedation will be analysed in *Study I* (see Section 6.2).

3.5. Psychosis: a pathological alteration of consciousness

While most of the naturally occurring, as well as cognitively- or pharmacologically- induced, ASCs can be experienced by any interested healthy individual, psychiatric or neurological patients may undergo disorder-related alterations of subjective experiences, for example, waking visual hallucinations in bipolar disorder (Baethge et al., 2005), or perceptual distortions during partial epileptic seizures (Johanson et al., 2008). Most of the pathological states of consciousness persist for relatively long periods of time, yet some of the alterations are relatively short-lasting, for example, visual migraine aura typically continues from 5 to 60 minutes (Viana et al., 2013). Notably, even though the extreme cases of pathological alterations of consciousness seem very odd, for example, bizarre delusions (Cermolacce et al., 2010), there is sometimes no clear-cut line separating pathological and normal experiences. For instance, there seems to be a continuum of paranoid thinking from occasional ungrounded suspicions in healthy individuals to fixed delusions in psychotic patients (Freeman et al., 2010, 2011).

Particularly intense and complex alterations of consciousness occur in psychosis, which can be broadly defined as the pathological presence of hallucinations and delusions (Bentall, 2007). Given that psychosis itself is not a categorized disorder but rather a set of symptoms observed in different psychiatric disorders, the more precise definitions of psychosis are disorder-specific. Thus, for example, in schizophrenia 'the term *psychotic* refers to delusions, any prominent hallucinations, disorganized speech, or disorganized or catatonic behavior' (American Psychiatric Association, 2000, p. 297), whereas in substance-induced psychotic disorder '*psychotic* refers to delusions or only those hallucinations that are not accompanied by insight' (American Psychiatric Association, 2000, p. 298). In schizophrenia, psychotic episodes are associated with intense changes in perception, cognition and/or emotions. Perhaps the most distinct perceptual disturbances in schizophrenia are auditory and verbal hallucinations ('voices') (Johns & McGuire, 1999), which are likely caused by abnormal activation levels of the auditory cortex and Broca's area (Kühn & Gallinat, 2012). However, visual (David et al., 2011) and olfactory (Arguedas et al., 2012) hallucinations may also be experienced by psychotic schizophrenic patients. Regarding reflective consciousness, psychosis in schizophrenia is often marked by reasoning abnormalities and complex delusions, i.e., false beliefs (Langdon et al., 2010). Emotional changes in schizophrenia can range from emotional withdrawal (Kay et al., 1987) to high levels of agitation (Marco & Vaughan, 2005). While schizophrenia can affect very broad aspects of phenomenal and reflective consciousness, some other psychiatric disorders primarily affect only a particular dimension of consciousness, for example, emotional alterations dominate in affective disorders (American Psychiatric Association, 2000).

Importantly, psychiatric or neurological disorders may be associated with changes not only in the baseline waking state, but also in the 'normal' ASCs, for example, psychotic patients with daytime delusions have an increased frequency of grandiosity topics in their dreams (D'Agostino et al., 2013). In this case, a paradoxical 'alteration of alteration' is encountered: patients' dreams may be different from dreams of healthy individuals, whose dreams in turn are different from their waking mentation. Possible alterations in the bizarreness of dreaming in psychotic schizophrenia patients will be investigated in *Study III* (see Section 6.4).

3.6. Unconscious states of mind

As discussed earlier, an *unconscious state* of mind contains no qualia, but maintains a potential to become conscious (see Section 2.1.6), which may provide important contrast conditions for studying the neural mechanisms of consciousness. A reversible unconsciousness may be a result of various neurological disorders, for example, a complete loss of consciousness is very typical but not always present after complex partial seizures in epilepsy patients (Johanson et al., 2003). Yet, perhaps the most common unconscious states are *dreamless sleep*, which will be investigated in *Study II* (see Section 6.3), and general anaesthesia or sedation, which will be explored in *Study I* (see Section 6.2). The loss of conscious experiences during dreamless sleep (Gillespie, 2002; Tononi & Massimini, 2008) is the only naturally occurring reversible fading of the stream of consciousness. The depth of sleep is typically assessed by visual scoring of polysomnographic (PSG) measurements, in particular EEG, electrooculography (EOG) and electromyography (EMG) activity patterns (Iber et al., 2007). Consciousness is often regarded to be lost when sleep EEG is dominated by the low frequency EEG delta activity (0.5–3 Hz). During deep NREM sleep, only a limited degree of integrated information is maintained in the cortex, which may prevent conscious experiences to emerge (Tononi, 2009). Up to 20% of sleep laboratory participants never report subjective experiences after awakenings from slow wave NREM sleep, and a further 30% of participants are very unlikely to report dreaming or mentation after awakenings from these stages of sleep (Cavallero et al., 1992).

Similarly to NREM sleep, deep anaesthesia is also associated with decreased high frequency activity (Tonner & Bein, 2006); however, this pattern is not universal and, for example, S-ketamine anaesthesia has increased spectral power in high rather than low frequencies (Maksimow et al., 2006). To monitor the depth of anaesthesia and sedation, various complex EEG-based indexes have been developed, the most commonly used of which is the bispectral (BIS) index. The BIS index is a non-linear combination of four different measures: the relative spectral power of the beta and gamma frequency range; the bispectral component of the broad frequency range; the 'QUAZI' suppression component; and the 'burst suppression' measure (Schneider, 2010). The BIS values from 100 to 80 indicate an awake state, 80 to 60 – sedation, 60 to 40 – anaesthesia, 40 to 20 – deep anaesthesia, and 20 to 0 – EEG burst suppression (Schneider, 2010). Generally, the lower the BIS index values are, the less likely it is that the patient is conscious (Kearse et al., 1998); however, intraoperative awareness may occur even when this BIS index is below the recommended value of 60 (Avidan et al., 2008). A further theoretical complication of the status of unconscious states arises from a possibility that the stream of consciousness may never be interrupted during deep sleep or general anaesthesia, for example, we may always dream in unresponsive states such as NREM sleep, but may not be able to recall it (Schredl et al., 2013). If so, the absence of reported subjective experiences may indicate a failure of memory rather than the absence of conscious experiences. Currently, there are no available empirical methods to confirm or exclude such possibilities.

3.7. Interactions between different alterations of consciousness

Even though each of the reviewed ASCs could be defined as a distinctive combination of the induction techniques and consequent alterations in perception, cognition, emotions and the underlying representational and neurobiological processes, some of the alterations seem to be phenomenologically analogous and perhaps may even share some of the neurocognitive mechanisms. For instance, Schwartz and Maquet (2002) pointed out that bizarre dreaming reminds many of the neuropsychological syndromes, such as misidentification of faces (Frégoli syndrome), places (reduplicative paramnesia), or loss of colour saturation (achromatopsia), suggesting that natural alterations of consciousness may temporarily replicate more persistent pathological ASCs. Lynn et al. (2012) argued that the depth of two major cognitively induced ASCs – hypnosis and meditation – could be modified by similar imaginative suggestions, and that both of these states could be successfully applied to train attention processing. Individual hypnotizability was also linked to habitual daytime sleepiness (Móró et al., 2011), showing that susceptibility to a cognitively induced ASC can be related to a trait of transition to a natural alteration of consciousness within the wake/sleep cycle.

Despite a number of somewhat sporadic comparisons (e.g., Lynn et al., 2012; Móró et al., 2011; Schwartz & Maquet, 2002) and several more systematic attempts to relate various alterations of consciousness (Hobson et al., 2000; Vaitl et al., 2005), contrastive analyses of different ASCs are still in a very premature state. Likewise, methods developed to study one of the alterations, for example, content analysis of subjective dream reports (Winget & Kramer, 1979), are seldom applied to study other states of consciousness. As encouraging exceptions, the content analysis methods are sometimes applied to study subjective reports of partial epileptic seizures (Johanson et al., 2008) and auditory hallucinations (Kent & Wahass, 1996) (for the content analysis of anaesthetic-induced experiences, see *Study I,* Section 6.2). Arguably, the major reason for this somewhat surprising neglect lies in methodological difficulties of finding suitable tools and experimental manipulations for systematic comparisons, either between a selected alteration of consciousness and a baseline state of consciousness, or between different ASCs. Most of the theoretical advancements in this thesis will be directed to the search for systematic associations between different states of consciousness (*Studies IV*, *V*, *VIII*, see Sections 6.5, 6.6, 6.9). Methodological limitations and possible solutions for studying ASCs are discussed in the following section.

4. EMPIRICAL METHODS OF STUDYING ALTERED STATES OF CONSCIOUSNESS

Experimental research of consciousness is limited by the *asymmetry of access* to subjective experiences (Velmans, 2007): while the empirical sciences of consciousness seek explanation of the mechanisms of consciousness from the objective *third-person perspective*, the experiencing subjects as participants of experimental studies can report the contents of their consciousness only from the subjective *first-person perspective* (Nagel, 1974). Given that the first-person data are not directly accessible by the third-person scientific methods, the asymmetry of access leads to a number of methodological obstacles that are specific to consciousness studies.

4.1. Facing the obstacles: introspection, reportability, baseline, and sampling

As long as the necessary and sufficient neural correlate of the phenomenal consciousness is unknown, the presence and the contents of subjective experiences in another person can only be reliably confirmed through a subjective report of a conscious agent, for example, by a button press (Salminen-Vaparanta et al., 2012), an eye blink (Marcel, 1993), a verbal answer (Schredl et al., 2009), or an act of mental imagery (Cruse et al., 2011). The most novel fMRI analysis methods can decode hemodynamic representations of visual experiences not only during waking but also during sleep onset, yet such experimental designs still rely on participants' confirmatory verbal reports (Horikawa et al., 2013). Naturally, progress of consciousness research largely depends on the accuracy of participants' *introspection*, i.e., 'thinking about one's primary conscious experiences […] for the purpose of describing and interpreting them' (Farthing, 1992, p. 58). Given that introspection depends on memory (James, 1890), it can be called a *retrospection*, i.e., thinking about remembered past experiences (Farthing, 1992), a paradigmatic example of which is a post-awakening reporting of dream experiences.

Introspecting participants are expected to be cooperative and trustworthy, i.e., they should not censor or confabulate their reports (Farthing, 1992), which is very complicated to control. These methodological constraints, i.e., reportability of the contents of consciousness and cooperativeness of the conscious agent, are particularly challenging when studying ASCs. For instance, reportability might be severely impaired due to limited meta-consciousness, i.e., explicit re-representation of the contents of consciousness (Schooler, 2002). In particular, hallucinating individuals might be so absorbed by unusual experiences that little resources are left to reflect on and verbalize their perceptual or cognitive experiences. Likewise, individuals experiencing alterations of consciousness may not be as cooperative and willing to report as they would be in a normal baseline state of consciousness, a paradigmatic example of which is the lack of cooperativeness of a depressed patient (Goekoop et al., 2009).

Furthermore, reportability might be completely lacking in unresponsive alterations of consciousness, such as sleep. In cases when an agent is unable or unwilling to report their experiences, a conscious person might be misjudged as unconscious (Mashour & LaRock, 2008), as unreportable or unreported mental processes might still be subjective, although unavailable for further cognitive and behavioural processing. In addition to sleep, other paradigmatic alterations with a possible dissociation between (un)responsiveness and (un)consciousness are general anaesthesia and vegetative or minimally conscious state (Boly et al., 2013). Unfortunately, given the methodological limitations of reportability and cooperativeness, there are very few studies that have systematically assessed the presence of subjective experiences in a well-controlled unresponsive state of the brain (but see *Study I*, Section 6.2).

Uncertain status of a baseline state of consciousness is yet another major obstacle that complicates research of the perceptual, cognitive and neural mechanisms of ASCs. Metaphorically, an alteration of consciousness could be defined as a significant diversion from the mainstream of consciousness, i.e., from a normal state of a healthy waking mind (see Sections 2.1.5 and 3.1). Yet, the choice of the normal baseline state against which an altered state should be identified and studied is uncertain, as there are no widely established settings (such as time of the day, body position, experimental task, etc.) under which the baseline state should be assessed. Consequently, it remains uncertain how strong the deviation of subjective experiences should be in order to be identified as an alteration of consciousness, for example, it is debatable whether diurnal fluctuations of perception (Alfuth & Rosenbaum, 2011), cognition (Marek et al., 2010), or emotions (Clark et al., 1989) would count as naturally occurring alterations of consciousness.

A further methodological complication arises when a contrast between a baseline waking state and an ASC is not feasible due to unresponsiveness of research participant. For instance, while the same time perception task could be carried out in hypnosis and in baseline waking state (Naish, 2001), it could not be performed by dreaming participants, unless they would become lucid (Erlacher & Schredl, 2004). In such cases, a different type of alteration could be used as a baseline contrast condition, for example, EEG studies aiming to find electrophysiological correlates of dreaming have tried to compare different sleep stages (Corsi-Cabrera et al., 2003), dreaming vs. dreamless sleep (Esposito et al., 2004), or to contrast different types of dreams (Nielsen & Chénier, 1999). Comparison of dreaming and dreamless sleep enables a sharp contrast between the presence and the absence of consciousness itself or its recall, as dreamless sleep might contain forgotten dreaming, as argued by Schredl et al. (2013). A contrast of dreams with varying frequency of selected experiences highlights a possibility of studying gradual transitions between different alterations of consciousness.

The major practical limitation of studying ASCs is inefficient data collection. Some of the ASC occur so seldom, for example, lucid dreaming, that it is almost impossible to study them experimentally, in which case studying a single well-trained participant might be an optimal choice (for a hypnotic virtuoso’s case study, see *Study VII*, Section 6.8). While other natural ASCs, such as REM sleep dreaming, may occur much more frequently, perhaps each night, only four or five measurements are usually possible during one night. *Study II* aimed to improve the efficiency of laboratory research of dreaming by introducing a serial awakenings paradigm (see Section 6.3). Finally, in addition to practical limitations, there are certain ethical restrictions to study some of the pharmacologically induced or pathological ASCs, as, for instance, research participants may not always have a cognitive and/or behavioural capacity to consent their participation or to withdraw from the study if they would wish so.

4.2. Content analysis of subjective reports

In laboratory research of dreaming, the reportability constraint is addressed by collecting subjective reports after participants are awakened (e.g., Schredl et al., 2009). Typically, verbal dream reports are audio-recorded and later transcribed for the content analysis of written texts, during which a rater identifies and classifies specific contents of dreaming, such as a number of live characters, or rates more complex features of dreaming, such bizarreness or lucidity. This way, subjective experiences within an ASC are evaluated outside of the alteration itself. Obviously, this approach has a number of introspection-related limitations, including forgetting, reconstruction errors, verbal description difficulties, censorship of intimate experiences, and lack of independent verification (Farthing, 1992), as well as errors made by the experimenter performing content analysis. While all of these limitations are methodologically challenging to deal with, the memory confound is particularly problematic in dream research, as sleepy participants may forget or censor certain dream experiences, or they may not even recall the presence of dreaming itself. Thus, a participant could report a state of dreamless sleep when in fact there was an intense, but forgotten, dream. Feasibility of such cases is supported by frequent occurrence of *white dreaming*, a state when an awakened person has a strong feeling that he or she was dreaming but does not recall any specific experience from the dream, which may happen in about 40% of awakenings from the early night stages 2 and 3 of NREM sleep (*Study II,* see Section 6.3). Hurlburt and Heavy (2004) described a number of methods that may improve the accuracy of reports of beep-interrupted waking mentation, for example, the beep should come from the participant's own natural environment. Similarly, awakening process should be well-controlled in dream research, as gradual awakenings from sleep result in higher rate of thought-like reports than do abrupt awakenings (Shapiro et al., 1963). Also, participants should be instructed to restrain their body movements after awakening, as motor activity can interfere with dream recall (Calkins, 1893).

In order to minimize content analysis errors, quantitative analyses are often carried out by several blind judges aiming at a strong inter-judge agreement (>75%), this way reducing possible bias in identification and classification of subjective experiences (e.g., Valli et al., 2005). Reliability assessment is particularly important when new content analysis scales or systems are devised (such as in *Studies I, II*, see Sections 6.2, 6.3). In addition to the reliability of dream content analysis, the validity of measurement should be assessed when possible (Kramer, 2007). Ideally, a dream scale should be content-valid, i.e., appropriate to the concept being measured. Further, a scale should show construct validity, i.e., it should be measuring the right construct and its different items should be related around the same construct or constructs. Finally, a valid dream scale should show predictive validity, i.e., it should be sensitive to detect the predicted research outcomes or hypothesized group differences. Unfortunately, formal psychometric analyses of dream content scales are seldom carried out (for a recent attempt, see Stumbrys et al., 2013). Given that neither experimenters nor awakened research participants have direct access to dream experiences, assessment of the content and construct validity of dream scales must rely on the poor memory and limited verbal reports of unique dreams. Unfortunately, well-controlled, repeated measurements are impossible in dream research, for instance, while doubtful measurements of hypnotic susceptibility could be repeated with the same individual on another day, sleep researchers do not have a privilege to ask their participants to undergo the same dream one more time. Thus, there is no direct way to check if the scale showing only negative emotions may have missed the positive ones that were experienced but forgotten.

Stability of dream content analysis is also inflated by a large intra-individual variability of dream characteristics, such as bizarreness and emotional tone (Schredl et al., 2001). It is recommended that at least 20 dream reports per individual should be collected in a short period of time in order to obtain reliable measures of dream content (Schredl et al., 2001), yet it is not always feasible in time-consuming laboratory studies of dreaming (efficiency of laboratory collection of dream reports will be addressed in *Study II*, see Section 6.3). If possible, highly motivated and introspective participants should be recruited for the laboratory studies of dreaming, as higher recall is associated with an individual's positive attitude towards dreams (Beaulieu-Prévost & Zadra, 2007). In addition, dream recall can be increased through training to pay attention to dreams, especially for the low and medium dream recallers (Schredl, 2002; Schredl & Doll, 1997).

Despite the suggested methodological improvements, it is necessary to acknowledge that dream research remains dependent on the limitations of subjective introspective reports. Two alternatives exist here: a simple sceptical solution would be to regard dream research as a non-scientific enterprise (e.g., Malcolm, 1959), yet this position ignores certain empirical facts about the world, i.e., the subjective reality of our dream experiences. Further, given that behaviouristic scepticism regards dreams as unsuitable objects for the science of empirical facts, a natural deduction from this position would be that dream experiences are not, or do not, depend on empirical, i.e., neurobiological, processes, which is not compatible with biological approaches that treat consciousness as an empirically and causally real phenomenon. Instead, a psychobiologically more plausible approach would be to continue developing introspection methods, aiming at as controlled and robust experimental designs as possible. Conscious states derived from introspective reports are often good predictors of human behaviours (Wilson, 2003), and as such they do generate descriptive categories that can be used in scientific hypotheses and theories. In fact, research using content analysis of dream reports has already yielded a number of well-replicated interesting findings (Barrett & McNamara, 2007), and other sciences that have to deal with subjective experiences may benefit from the adaptation of dream research methods. For instance, studies of anaesthesia dreaming typically evaluate only the presence or absence of subjective experiences without analysing further the contents of phenomenal consciousness (e.g., Leslie et al., 2009). Arguably, research of consciousness alteration during sedation and anaesthesia would benefit a lot from the application of dream analysis methods (as was done in *Study I*, see Section 6.2).

4.3. Behavioural methods to study alterations of consciousness

Instead of collecting and analysing verbal introspective reports, consciousness can be investigated by behavioural methods, for example, by analysing participants' responses in stimuli detection or discrimination experiments (Braun & Julesz, 1998; Fisk & Haase, 2005). In a typical behavioural experiment of the contents of consciousness, physical stimuli are presented at the threshold level of awareness, and participants are asked to report if they perceived the stimulus or not (detection tasks), or alternatively, which of the several possible stimuli did they experience (discrimination tasks). By systematically manipulating physical properties of stimuli, for example, the duration of targets (Pessoa et al., 2005), and/or cognitive functions, such as expectancy and attention (Koivisto & Revonsuo, 2007), and analysing how these manipulations are reflected in behavioural measures of awareness, a large range of questions can be investigated, such as: what is the temporal order of awareness of different visual features (Zeki & Bartels, 1999); is awareness necessary for top-down attention and working memory (Hsieh & Colas, 2012); how does preceding unconscious or non-conscious processing modulate subsequent conscious awareness (Peremen et al., 2013); and is conscious perception gradual or dichotomous (Overgaard et al., 2006; Sergent & Dehaene, 2004). The presence of specific contents of consciousness is typically assessed by the dichotomous 'yes' or 'no' responses, for example, by measuring the hit rate in a certain condition or calculating more complex signal detection measures, such as discriminability and response criterion (Ricci & Chatterjee, 2004). In addition to dichotomous responses, other behavioural measures can also be used to assess the consciousness, including reaction times (Kentridge et al., 2008) or, for instance, a temporal rate of perceptual reversals in response to the presentation of ambiguous figures (Intaitė et al., 2013). Further, several awareness-specific behavioural measures may be used to assess phenomenal consciousness more accurately, such as confidence ratings of target visibility, which enables more differentiated analysis of subjective experiences, for example, visual awareness of stimulus presence can be compared with more complex awareness of stimulus type (Salminen-Vaparanta et al., 2012).

Similarly to the experiments of the contents of consciousness in a typical waking state, behavioural measures can be applied to study ASCs. For instance, individuals can perform the same cognitive task in a baseline state and an ASC or in several different ASCs, which would allow a contrast of cognitive processes in different states of consciousness with phenomenal contents being relatively well-controlled and largely driven by experimental stimuli (for such a contrast between time perception in hypnosis and baseline waking state, see *Study VII*, see Section 6.8). However, even though paradigms using behavioural methods have much higher control of the phenomenal contents of consciousness than experiments relying on the content analysis methods (see Section 4.2), they still largely rely on the accuracy of participants' introspection. In dream research, participants introspect their subjective experiences and then give a verbal report, whereas in behavioural studies they have to report their introspection by a motor response, unless it is a speeded reaction times task. Notably, analysis of verbal reports enables multidimensional measurement of relatively complex subjective experiences, whereas behavioural methods typically focus on a very narrow aspect of phenomenal or access consciousness, ignoring the broader spatial and temporal unity of consciousness (see Section 2.2). However, behavioural methods allow rapid sampling of the same type of subjective experiences, and provide tools for studying interaction between consciousness and other mental functions. Thus, more powerful cognitive and statistical analyses are possible in behavioural studies than those available for the content analysis studies.

4.4. Neuroimaging of altered states of consciousness

The two major approaches to study the neural mechanisms of consciousness include experimental designs focusing on the selected contents of consciousness, and paradigms designed to study the overall states of consciousness (Dehaene & Changeux, 2011; Rees & Frith, 2007). The first class of studies may present stimuli close to threshold (Kim & Blake, 2005; Macknik, 2006) or, for instance, show ambiguous stimuli with alternating perceptual interpretations (Kleinschmidt et al., 2012; Kornmeier & Bach, 2012), and then contrast brain responses between trials that differ in awareness of these stimuli. The second class of experiments typically contrasts evoked responses or spontaneous brain activity between the baseline state of consciousness and different ASCs, such as sleep (Massimini et al., 2010), sedation (Långsjö et al., 2012), and minimally conscious states (Boly et al., 2004). The most widely used neuroimaging methods to study ASCs are EEG, which records electrical brain activity along the scalp (e.g., Voss et al., 2009), fMRI, which measures cerebral blood flow coupled with neuronal activity (e.g., Owen et al., 2006), positron emission tomography (PET), which detects blood flow or glucose metabolism (e.g., Boly et al., 2008), and combined transcranial magnetic stimulation (TMS)-EEG, which can assess cortical information flow in response to transcranial perturbation of spontaneous electric activity (e.g., Massimini et al., 2012). It has been argued, however, that the aforementioned neuroimaging methods are very unlikely to solve the hard problem of consciousness, as they are spatially and/or temporally too coarse to detect the electrophysiologically complex phenomenal level of organization in the brain (Revonsuo, 2001). For instance, the speed of neurobiological processes constituting consciousness is much faster than the speed of measurement of fMRI or PET scanning, whereas the sources of EEG signals registered on the scalp are largely unknown.

Nevertheless, the neuroimaging studies have helped to detect a number of neural correlates (even though not constituents) of altered consciousness, such as a functional recoupling of subcortical and fronto-parietal regions upon regaining consciousness after anaesthetic-induced unresponsiveness (Långsjö et al., 2012). A recently developed perturbational complexity index (PCI), a TMS-EEG measure of cortical information integration and differentiation (see Section 2.5.5), can be used to distinguish different levels of consciousness in sedation, sleep, and traumatic brain injury (Casali et al., 2013). Yet, many such types of studies conflate consciousness with responsiveness and do not systematically assess if unresponsive participants still have internally generated subjective experiences (Mashour & LaRock, 2008, see also *Study I*, Section 6.2). Arguably, instead of focusing on the raw comparison between the baseline and ASCs, a direct contrast between brain activity related to different types of spontaneous subjective experiences when the brain state is controlled, such as different types of dreams or dreaming vs. dreamless sleep when the sleep stage is kept the same (see *Study II*, Section 6.3), is more eligible to reveal the neural mechanisms of altered phenomenal consciousness. The earlier attempts to start the neurophenomenology programme of research, which would systematically match the first-person data with the large-scale neurodynamics (Varela, 1996), did not flourish, largely because of the methodological limitations and biases related to the first-person reports (Lutz & Thompson, 2003). This program was also heavily anchored to the philosophical tradition of phenomenology (Petitot et al., 1999), the concepts and metaphysical assumptions of which were not intuitive for empirical scientists to accept. It is expected that *Studies I–VI* (see Sections 6.2–6.7) will contribute to the development of more controlled and efficient analysis of the first-person reports, eventually leading to the more rigorous neuroimaging studies of ASCs.

5. AIMS OF THE PRESENT THESIS

The main purpose of this thesis was to investigate subjective experiences and cognitive processes in four different types of alterations of consciousness: naturally occurring dreaming, cognitively induced hypnosis, pharmacologically induced sedation, and pathological changes of consciousness in schizophrenia. More specific goals of the thesis were:

1. To empirically verify the dissociation between consciousness as responsiveness and consciousness as the presence of subjective experiences (*Study I*, see Section 6.2).

2. To develop and test new content analysis methods for mapping phenomenology in unresponsive states, such as pharmacologically induced sedation (*Study I*, see Section 6.2) and natural sleep (*Study II*, see Section 6.3).

3. To develop an efficient laboratory paradigm for conducting awakenings and collecting data for a contrast between dreaming and dreamless NREM sleep (*Study II*, see Section 6.3), and to propose novel approaches for a contrast between lucid and non-lucid dreams (*Study VI*, see Section 6.7).

4. To contrast dreaming and waking mentation reports collected from psychotic schizophrenia patients and healthy controls (*Study III*, see Section 6.4), and to develop a conceptual framework of how these natural and pathological alterations might be related (*Study IV*, see Section 6.5).

5. To analyse whether dreaming can be treated as a research model of psychotic and/or intact waking state of consciousness (*Study V*, see Section 6.6).

6. To investigate time perception distortions under cognitively induced hypnosis (*Study VII*, see Section 6.8), and to develop a theoretical framework of how such distortions might be associated with other ASCs that undergo similar changes in time perception (*Study VIII*, see Section 6.9).

6. ORIGINAL STUDIES

6.1. General overview

Deriving from the formulated goals, both empirical and theoretical research were carried out in the present thesis (for an overview of all studies, see Table 1). Theoretical studies (*IV–VI, VIII*, see Sections 6.5–6.7, 6.9) reviewed scientific literature and suggested new ways of how research of different ASCs could be advanced and integrated. Empirical studies (*I–III, VII*, see Sections 6.2–6.4, 6.8) focused on the specific contrasts between two or more states of consciousness (for an overview of contrasted states of mind, see Table 2). Experimental paradigms and methods used in these studies are described in the following sections.

Table 1: General overview of empirical and theoretical studies.

Studies	Participants	Rationale	Methods	Publication type
I	40	To analyse subjective experiences occurring under unresponsive sedation and to demonstrate discrepancy between different definitions of conscious states.	• Experimentally induced sedation. • EEG-derived analysis of sedation depth. • Content analysis of introspective reports.	Peer-reviewed empirical article.
II	5	To develop a new laboratory paradigm to efficiently collect data for a contrast between minimal NREM dreaming and dreamless sleep.	• PSG. • EEG analysis. • Content analysis of dream reports.	Peer-reviewed empirical article.
III	10	To analyse bizarreness in dreams and to compare overall similarity of dreaming and spontaneous waking mentation in healthy individuals and psychotic patients.	• Assessment of psychotic symptoms, memory functioning and sleep structure. • Content analysis of dream reports. • Blind categorization of dream and waking mentation reports.	Peer-reviewed empirical article.
IV	-	To draw a formal scheme of how dreaming and schizophrenia might be related.	A theoretical paper.	An extended invited commentary on Zanasi, M., Calisti, F., Di Lorenzo, G., Valerio, G., & Siracusano, A. (2011a). Oneiric activity in schizophrenia: Textual analysis of dream reports. *Consciousness and Cognition*, 20, 337–348.
V	-	To evaluate theoretical and empirical feasibility of using dreaming as a research model of waking consciousness and/or psychosis.	A theoretical paper.	Peer-reviewed review article.

Studies	Participants	Rationale	Methods	Publication type
VI	-	To develop experimental hypotheses for studying dream lucidity and its neural correlates by focusing on non-lucid or pre-lucid dreams.	A theoretical paper.	An extended invited commentary on Hobson, A. (2009). The neurobiology of consciousness: Lucid dreaming wakes up. *International Journal of Dream Research*, 2, 41–44.
VII	1	To compare perception of duration under hypnosis and in the baseline waking state.	• Hypnotic induction. • Psychophysical assessment of duration perception. • Cognitive modelling of behavioural data.	Peer-reviewed empirical article.
VIII	-	To propose a formal model of how pathological, cognitively and pharmacologically induced, and natural distortions of time perception might interact.	A theoretical paper.	Invited book chapter.

Table 2: Experimental contrasts between alterations of consciousness, baseline waking states and unconscious states of mind.

Studies	Naturally occurring ASCs	Cognitively induced ASCs	Pharmacologically induced ASCs	Pathological ASCs	Unconscious states	Baseline waking consciousness
I			Dexmedetomidine sedation dreaming. Propofol sedation dreaming. Sevoflurane sedation dreaming. Xenon sedation dreaming.		Dreamless dexmedetomidine sedation.	
II	NREM sleep dreaming.				NREM dreamless sleep.	
III	Natural sleep dreaming.			Psychotic sleep dreaming. Psychotic waking mentation.		Natural waking mentation.
VII		Cognition in neutral hypnosis.				Baseline waking cognition.

6.2. Study I: Consciousness lost and found: Subjective experiences in an unresponsive state (Noreika et al., 2011)

6.2.1. *Methods*

Anaesthesiological definition of consciousness equates it with responsiveness, yet it is conceivable to assume that an unresponsive individual may be subjectively conscious (Mashour & LaRock, 2008). To test a hypothesized dissociation between the presence of subjective experiences and responsiveness in pharmacologically induced alterations of consciousness, 40 right-handed male volunteers (age: M=23.3, SD=2.7; American Society of Anesthesiologists physical status I) were sedated in *Study I*. Four participant groups were formed with the following sedative/anaesthetic drugs used to induce sedation: dexmedetomidine group – 10 participants (2 sessions each); propofol group – 10 participants (2 sessions each); sevoflurane group – 10 participants (1 session each); and xenon group – 10 participants (1 session each). During all sessions, the depth of sedation was monitored with an EEG-derived BIS index (BIS XP, algorithm version 4.0, smoothing rate 15 s, Aspect Medical Systems). BIS index is calculated from a signal recorded from an electrode strip attached to the forehead, and it ranges from 0, which reflects isoelectric EEG silence, to 100, which is observed when an adult participant is fully awake and alert (see Section 3.6).

Concentration of a dexmedetomidine, propofol or sevoflurane was stepwise increased until the loss of responsiveness (LOR). LOR was defined by an absence of behavioural response to a verbal command 'Open your eyes!', which was requested at 5 min intervals. Due to pharmacokinetic properties of xenon, its sedation was induced more abruptly. After discontinuation of drug delivery, the regaining of responsiveness (ROR), i.e., the first meaningful response to the verbal command 'Open your eyes!', was assessed for each drug group at 1 min intervals. ROR confirmation was followed by resting EEG recording that lasted for 5 min. Afterwards, a structured interview was taken from each participant regarding subjective experiences during sedation. The interview was repeated after 10–30 min, when participants had recovered from sedation.

For the analysis of frequency and quality of subjective experiences in post-sedation reports, the *Subjective Experiences During Anaesthesia Coding System* (SEDA-Coding) was developed. SEDA-Coding distinguishes 3 categories of subjective experiences: (1) micro-level experiences (visual, auditory, sensorimotor, olfactory, gustatory, positive affective, negative affective, thought-like); (2) macro-level experiences (dream-like, laboratory-related, out-of-body experiences, changed experience of time); and (3) white reports when participant remembers having had some experiences but cannot recall any specific details.

6.2.2. *Results*

Content analysis of interviews showed that subjective experiences were reported in 58.6% of sedation sessions. When reports of the first session were compared across sedative/anaesthetic agents, the difference in the frequency of reports with subjective contents approached significance (Fisher's exact test: $p=.057$, $N=40$). Individual drug comparisons showed that dexmedetomidine sedation was accompanied by higher incidence of reports with subjective experiences than propofol sedation (Fisher's exact test: $p<.05$, $N=20$). Regarding content categories of SEDA-Coding, the four sedative/anaesthetic agents differed in the frequency of reports with laboratory-related experiences (Fisher's exact test: $p<.05$, $N=40$). Individual drug comparisons showed that sevoflurane sedation induced more experiences related to laboratory, medical team and hospital than dexmedetomidine sedation (Fisher's exact test: $p<.01$, $N=20$).

Analysis of averaged BIS values showed significant differences between propofol, dexmedetomidine and sevoflurane sedation during the loss of responsiveness period (repeated measures ANOVA: $F(2,27)=5.79$, $p<.01$). In particular, BIS values were lower, suggesting a deeper sedation, during propofol (M=60.54) than during sevoflurane (M=70.00) sessions (independent t test: $t(18)=2.99$, $p<.01$, $d=1.41$). Similarly, BIS values were lower during dexmedetomidine (M=55.10) than during sevoflurane (M=70.00) sessions (independent t test: $t(18)=2.94$, $p<.01$, $d=1.39$). Yet, even though dexmedetomidine sedation was accompanied by higher frequency of reports with subjective experiences than propofol sedation, the BIS values did not differ between these two agents during the loss of responsiveness period (independent t test: $t(18)=1.07$, $p=.298$). This finding indicates independence of the 'depth' of sedation required to maintain unresponsiveness as measured by the BIS index and the occurrence of subjective experiences during sedation in between-agent comparisons.

Within-agent comparison between sessions with the presence of subjective experiences and sessions with their absence during a period of dexmedetomidine-induced unresponsiveness showed higher BIS values and shallower sedation when experiences were present (M=58.60, SD=15.63) compared to sessions when they were absent (M=47.01, SD=12.80) (paired samples t test: $t(4)=4.58$, $p=.01$, $d=2.05$). Given that the depth of sedation did not differ between the presence and absence of subjective experiences during the induction phase (paired samples t test: $t(4)=-.87$, $p>.05$) or the recovery phase (paired samples t test: $t(4)=1.14$, $p>.05$) of dexmedetomidine sessions, these findings provide indirect evidence that subjective experiences occurred during the actual period of unresponsiveness. Similar inferential statistical analyses were not carried out with other anaesthetic agents due to a low number of observations in one of the comparison conditions.

6.3. Study II: Early-night serial awakenings as a new paradigm for studies on NREM dreaming (Noreika et al., 2009)

6.3.1. *Methods*

Aiming to develop an efficient paradigm for studying alterations of consciousness during sleep and to describe perceptual complexity and dynamics of NREM sleep dreaming, five volunteer students were recruited to take part in *Study II* (age: M=23.7, 4 females). Each of them spent one adaptation night and four non-consecutive experimental nights in the sleep laboratory. A novel paradigm, called the early-night serial awakenings (ENSA), was applied during experimental nights, with up to 12 awakenings each night from NREM sleep Stages 2 and 3 during the first 2–4 hours of sleep. Scoring of sleep stages was based on the recordings from two EOG and four EEG electrodes (C3, C4, O1, O2). To evaluate the homogeneity of data across the serial awakenings produced by the ENSA paradigm, a quantitative EEG analysis of possible changes in the spectral power of different frequency bands (delta: 0.5–4.0 Hz, theta: 4.0–8.0 Hz, alpha: 8.0–12.0 Hz, beta1: 12.0–16.0 Hz, beta2: 16.0–32.0 Hz) was carried out with the Brain Vision Analyzer (v1.05.0002) software.

After each awakening, participants were asked to report 'everything that was going through their mind before awakening'. If participants reported at least one perceptual experience, a set of further 18 questions was given, including questions about objects and the self in a dream. Two blinded judges carried out content analysis of post-awakening reports and separated three recall categories: (1) reports of dreamless sleep, if participant did not report any perceptual experience; (2) reports of white dreaming, if participant remembered having a dream, but could not recall any concrete perceptual experiences; and (3) dream reports, if participant reported at least one perceptual experience. Complexity and temporal dynamics of perceptual experiences in dream reports were further analysed according to the *Orlinsky's Modified Scale for Perceptual Complexity of Dreams* (O-PC-Dreams, following Orlinsky, 1962). The O-PC-Dreams consists of 7 categories that describe an overall perceptual complexity of subjective reports, ranging from category 1, when participant recalls only a single isolated experience, to category 7, when he or she remembers a complex dynamic dream with several changes of scenery. Categories 1–4 refer to temporally static dreams, whereas categories 5–7 refer to temporally dynamic dream experiences (see Table 3).

Table 3: Orlinsky's Modified Scale for Perceptual Complexity of Dreams (O-PC-Dreams).

Categories of perceptual dynamics	Categories of perceptual complexity	Examples
Static dream: person experiences only static percepts and/or never-ending repetitive actions that do not accumulate into major perceptual changes.	1. Person remembers a specific topic but in isolation: a fragmentary percept, unrelated to anything else.	'There was a boy.'
	2. Person remembers several unrelated perceptual experiences.	'There was a boy as well as a sound of water flow.'
	3. Person remembers several interconnected perceptual experiences.	'There were several boys sitting on the boat.'
	4. Person remembers a short but coherent dream, the parts of which seem to be immersed within a unified scene.	'There were several boys sitting on the boat in a river. It was a very sunny day.'
Dynamic dream: person experiences dynamic changes, during which something happens, followed by some consequence or in which one perceptual experience – object, scene, or main interacting character – is replaced by another.	5. Person remembers a coherent dream, in which something happens within a unified scene, i.e., one perceptual experience is replaced by another.	'There were several boys sitting on the boat in a river. It was a very sunny day. Then one of them invited me to join them and so I did – I was very happy about it.'
	6. Person remembers a long, detailed dream in which the whole scene is replaced by another scenery.	'There were several boys sitting on the boat in a river. It was a very sunny day. Then one of them invited me to join them and so I did – I was very happy about it. We navigated downstream for a while, and stopped near the riverside restaurant. The restaurant had Eastern décor with bright colours.'
	7. Person remembers a long, detailed dream in which the whole scene is replaced by another scenery more than once.	'There were several boys sitting on the boat in a river. It was a very sunny day. Then one of them invited me to join them and so I did – I was very happy about it. We navigated downstream for a while, and stopped near the riverside restaurant. The restaurant had Eastern décor with bright colors. Suddenly, one stranger in the restaurant became very large and scary. I was afraid of him and ran outside, which appeared to be a city with shining lights and busy streets [etc.].'

6.3.2. *Results*

The ENSA paradigm appeared to be practically feasible and data-wise very efficient. On average, 8.2 (SD=2.6) awakenings were performed during 20 experimental nights (164 awakenings as a total), with a mean total recording time of just 193 mins (SD=57.4) per single night. There were only 23.5 mins (SD=14.7) on average between two adjacent awakenings. During pilot stages of the project a concern was raised of whether participants will be able to fall asleep after serial awakenings due to repetitive disruption of normal circadian patterns. However, the opposite effect was observed in the main experiment: there was a strong negative correlation between the sleep latency and the count of previous awakenings (Spearman's rank order correlation: rho=−.98, n=8, p<.001), i.e., the more awakenings the participants underwent, the shorter time it took for them to fall asleep again. To investigate possible changes in spectral power between the early ENSA awakenings (1–4 awakenings) and the late ENSA awakenings (5–12 awakenings), separate 2×4×5 ANOVA tests were carried out for Stages 2 and 3 of NREM sleep with the following factors: Awakenings (2: early ENSA, late ENSA), Electrodes (C3, C4, O1, O2) and EEG bands (delta, theta, alpha, beta1, beta2). The main effect of Awakenings as well as the interactions between the Awakenings and Electrodes or EEG Bands were non-significant, indicating a high stability of spectral power patterns across the ENSA sessions.

27 awakenings and subjective reports were excluded from further analysis due to various technical problems, and a total of 137 NREM sleep reports were processed further for dream content analysis. Analysis of inter-rater judgments indicated strong agreement in scoring of reports for the recall categories (89.8% of reports; Cohen's kappa coefficient test: κ=.85) and for the categories of perceptual complexity of dreams (78%; κ=.88). Proportions of different types of reports between sleep stages were as follows: 23.8% of dreamless, 52.4% of white dreaming and 23.8% of dream reports after Stage 2 sleep awakenings; 37.3% of dreamless, 35.2% of white dreaming, and 27.5% of dream reports after awakenings from transitional stage of sleep (which was defined by the first appearance of delta EEG waves); and 29.6% of dreamless, 31.8% of white dreaming, and 38.6% of dream reports after Stage 3 sleep awakenings. Notably, percentage of white dream reports significantly decreased from Stage 2 to transition to Stage 3 sleep (one-way ANOVA: $F(1.88,7.53)=7.15$, $p<.05$, $\eta^2=.64$; all pairwise comparisons: $p<.05$). These findings suggest that NREM Stage 3 might be the most suitable period of sleep for awakenings that aim to produce comparably high proportions of dreaming and dreamless sleep reports. Content analysis using O-PC-Dreams indicated that majority of 41 NREM dream reports were perceptually simple and static: five dreams fell under category 1, two dreams under category 2, eighteen dreams under category 3, fourteen dreams under category 4, and only two dreams fell under dynamic category 5.

To contrast EEG activity between dreaming and dreamless sleep, a follow up study was carried out using a higher density EEG setup (25 electrodes) and the same ENSA paradigm. A similar efficiency of the data collection was achieved with 10 new participants providing a total of 322 reports. Results of this study have not been included in this dissertation as they are still being analysed.

6.4. Study III: Dream bizarreness and waking thought in schizophrenia (Noreika et al., 2010a)

6.4.1. *Methods*

Bizarreness of dream experiences seems to remind psychotic perception and cognition observed in schizophrenia patients (Kelly, 1998), pointing to phenomenological similarities between naturally occurring and pathological ASCs. To test the bizarreness level in dreams of psychotic patients, and the resemblance of their waking and sleep mentation, five male schizophrenia inpatients (age: M=34.8, SD=6.3) and five male members of the nursing staff working at the same hospital (age: M=33.2, SD=6.5) took part in *Study III*. Inclusion criteria for the patients' group were unambiguous diagnosis of schizophrenia, current psychosis with positive symptoms, and well-preserved cognitive functioning, which was assessed by experienced psychiatrist. Cognitive functioning of all participants was tested with a detailed neuropsychological battery: WAIS tests Similarities, Digit span forward, Digit span backward, Digit symbol, Block design, 20 objects naming time, 20 objects immediate recall, 30 paired word associates; Benton Visual Memory test; clinical semantic and phonological fluency tests; and the Mini-Mental State Examination. For further assessment of memory functioning, in particular the recall of perceptual experiences, an ecologically valid experimental test was developed. Participants were asked to view a 5-min video recording of people behaving in ordinary situations, and afterwards to write down everything that they could recall from the video. Furthermore, to exclude possible sleep disorders, patients were monitored for one night with the static charge sensitive bed (SCSB) and actometers combined with video observation. Even though the SCSB-assessed quality of sleep varied from patient to patient, all patients had both quiet and active sleep, and there were no indications of sleep disorders.

Following clinical assessment, all participants were instructed to collect five dream reports by keeping a written dream diary after natural morning awakenings. Waking thought reports were collected on five different days by bringing participants to a silent dim room, letting them relax on a bed, and after 10 mins asking them to write down everything that was going through their mind. Four blind judges classified all dream and waking reports across two axes: origin of report (dream/waking thought) and reporter (patient/control). This classification was unguided, i.e., the judges were not provided with formal scoring guidelines and had to make judgments based on their own subjective criteria. In addition, two judges analysed dream reports more formally with the *Content Analysis of Bizarreness scale* (Revonsuo & Salmivalli, 1995). This scale evaluates ratios between the bizarre and the non-bizarre occurrences of basic dream elements for three different types of bizarreness: incongruity, which refers to a dream element inconsistent with waking reality; vagueness, which refers to an obscure or indeterminate element; and discontinuity, which refers to an element suddenly (dis)appearing or transforming. The agreement in bizarreness classification was 78% for the patients' and 86% for the controls' dream reports.

6.4.2. *Results*

Each of the control participants wrote down five dream reports, whereas the patients reported on average 6.8 dreams. The length of dream reports was significantly shorter in the patient group (M=71 words, SD=64.5) than in the control group (M=201 words, SD=114.4) (Wilcoxon rank-sum test: W_s=727, p<.001). Arguably, the shorter length of dream reports in the patient group did not depend on the more mundane dream contents, but rather on the poorly functioning memory of semantic and perceptual experiences, which was evidenced by several memory tests. In particular, the patient group performed worse than the control group in the WAIS test for immediate recall of paired word associates (independent t test: t(8)=3.2, p<.05) and the Benton Visual Memory test (t(8)=2.9, p<.05). Furthermore, patients gave significantly shorter reports of the 5-min video recording (word count: M=54, SD=32) than did control participants (M=122.2, SD=41.5) (independent t test: t(8)=2.9, p<.05).

The blind judges made only one mistake in distinguishing dream reports from waking thought reports for the control group. However, the same judges misjudged that 52.9% of dream reports represent waking thoughts for the patients group compared to no mistakes for the controls (Pearson chi-square test: χ^2=16.6, df=1, p<.001). Similarly, the judges decided that 48% of patients' waking thought reports are dreams, compared to 4% of such mistakes for the control group (χ^2=10.4, df=1, p<.01). These findings indicate that overall content of reported subjective experiences did not differ between nocturnal dreaming and waking consciousness in psychotic schizophrenia patients. Regarding the reporter of subjective reports, the judges could not distinguish patients and controls, as many of the patients' waking reports were treated as standard dreams of control participants. Content analysis of dream reports using the Bizarreness scale showed that 33.2% of dream elements were bizarre in the patient group, compared to 20.7% of such elements in the control group (χ^2=38.1, df=1, p<.001). The largest differences between the study groups were in the Incongruity (χ^2=21.3, df=1, p<.001) and Vagueness (χ^2=43.0, df=1, p<.001) categories of subjective content bizarreness.

6.5. Study IV: Dreaming and waking experiences in schizophrenia: How should the (dis)continuity hypotheses be approached empirically? (Noreika, 2011)

6.5.1. *Literature review*

Empirical findings regarding subjective contents of dreaming in schizophrenia patients are often interpreted in the framework of the *continuity hypothesis* (e.g., Kramer & Roth, 1973; Stompe et al., 2003; Zanasi et al., 2011a). Most generally, the continuity hypothesis suggests that subjective experiences in dreaming are modulated by or are a reflection of subjective experiences during wakefulness (Schredl, 2003). For instance, Schredl and Hofmann (2003) showed that the amount of time spent driving a car and reading during wakefulness correlates positively with frequency of these activities in dreams. Following a similar theoretical background, Zanasi et al. (2011a) compared dream reports of 123 schizophrenia patients and 123 healthy individuals using linguistic textual analysis methods. Some of their findings, such as a decreased frequency of hearing-related lemmas in schizophrenia dreams, were interpreted as reflecting schizophrenia-related impairments during wakefulness. In particular, the reduced frequency of hearing words in dream reports of schizophrenia patients was hypothetically related to the auditory memory deficits, which are frequently observed in schizophrenia patients during wakefulness (Zanasi et al., 2011a). In *Study IV*, the continuity interpretation of schizophrenic dreams was critically examined, arguing that it is not fully substantiated in Zanasi et al. (2011a) as well as in several other studies on schizophrenia dreaming.

6.5.2. *Original proposal*

Conceptually, interaction between dream and waking experiences could have a form of 'continuity', 'discontinuity' or 'independence'. Continuity hypothesis would be supported by a positive correlation of rates of certain experiences, for example, meeting strangers, in dream and waking thought reports. Causally, continuity hypothesis could be further divided into the 'waking-to-dreaming' hypothesis, which states that a frequent occurrence of certain waking experiences increase the frequency of their occurrence in dreams (e.g., Schredl & Hofmann, 2003), and the 'dreaming-to-waking' hypothesis. In the context of psychosis studies, the latter hypothesis would state that certain dream experiences might intrude into waking consciousness (e.g., Hempel et al., 2003). Contrary to the continuity hypothesis, discontinuity hypothesis would predict a negative correlation between the frequencies of certain type of experiences in waking and dream reports (e.g., Cartwright, 1972), possibly referring to a hypothetical compensatory mechanism that stabilizes the total rate of certain experiences. For example, increase in the frequency of certain dream experiences might be related to their decrease during wakefulness in a case of the 'compensated waking' discontinuity, and the opposite would be true in a case of the 'compensated dreaming' discontinuity. Finally, the independence hypothesis would predict no association between waking and dreaming experiences.

Importantly, these possibilities are not mutually exclusive and while some of the experiences may show mismatch between different states of consciousness, other experiences may be continuous or vary independently between the states of consciousness under investigation. Thus, even though there is an increasing evidence for the continuity between waking and dreaming in psychosis (Arnulf et al., 2000; Hempel et al., 2003; Vita et al., 2008), some of the experiences may be discontinuous or independent. For example, the reduced frequency of hearing-related words in dream reports of schizophrenia patients (Zanasi et al., 2011a), which was originally interpreted by the authors as reflecting continuity with the auditory sensory memory deficits found in schizophrenia during wakefulness (e.g., Kasai et al., 2003), may have an alternative explanation. In particular, it is known that up to 74% of schizophrenia patients report elevated levels of auditory hallucinations, or 'voices', during wakefulness (Sartorius et al., 1974). Therefore, reduced hearing experiences in dreams might balance out increased levels of auditory hallucinations in waking life, as predicted by the hypothetical compensatory discontinuity of mental contents. Zanasi et al. (2011b) replied that such a suggestion does not take into consideration that schizophrenia patients tend to have not only auditory but also visual hallucinations, while no reduction of sight-related words was observed in their dream reports, which is not compatible with the 'compensatory hypothesis'. A further response to their reply would be that perceptual and cognitive interactions between different states of consciousness are multidimensional and that the discontinuity of auditory experiences does not exclude a possible independence or continuity of visual experiences.

6.6. Study V: How to integrate dreaming into a general theory of consciousness – A critical review of existing positions and suggestions for future research (Windt & Noreika, 2011)

6.6.1. *Literature review*

As the most frequently occurring natural ASC, dreaming could be regarded as an important phenomenon for testing predictions derived from the dominating theories of consciousness. However, recent attempts to integrate research of dreaming with the mainstream cognitive neuroscience of consciousness and cognition (Hobson et al., 2000; Nir & Tononi, 2010; Revonsuo, 2006; Schwartz & Maquet, 2002) did not yield yet straightforward results. The most programmatic yet rather contradictory suggestions treat dreaming as a model system continuous or similar either with the standard waking consciousness (Revonsuo, 2006) or with the pathological wake states (Hobson et al., 2000). Formally, dreaming can function as a research model of the explanatory target in at least three different ways: as a global model (when it replicates all or most of the central features of the explanatory target); as a restricted model (when it replicates some of the features of the explanatory target); or as a model via negative analogy (when it is systematically dissimilar from the explanatory target).

Perhaps the most detailed proposal of how to treat dreaming as a research model of waking consciousness was developed by Revonsuo (1995b, 2000, 2006), who argued that dreaming is a pure form of consciousness, isolated from ontologically confounding sensory inputs and motor outputs, yet containing the fundamental properties of consciousness, such as the presence of multimodal sensory experiences and an immersion in the world simulation. Given that subjective qualities of dreaming are continuous with the subjective qualities of waking consciousness (Revonsuo, 2006), the former could be regarded as a global model of the latter. From this perspective, analyses of the functional organization and neural mechanisms of dreaming are expected to identify the fundamental properties of waking consciousness. While agreeing on the usefulness of dreaming as a simplified domain for studying waking consciousness, Churchland (1988) took an antagonistic approach to that of Revonsuo (2006) and argued that there are characteristic differences between dreaming and wakefulness, such as the level of cognitive bizarreness. Consequently, dreaming can be treated as a model of wakefulness via negative analogy, which may reveal systematic differences between these states of consciousness. In this case modelling relationship may show that there is no single homogeneous underlying organizing principle of consciousness.

Hobson (1996, 1999, 2001) argued that hallucinations and cognitive deficiencies demarcate dreaming from the standard waking consciousness. However, dreaming can still be regarded as a global model of conscious mind, yet not of its intact form, but of pathological psychoses, for example, delirium tremens. In addition to similar phenomenology, both dreaming (or rather REM sleep) and clinical delirium are marked by a shift towards cholinergic neuromodulation of the brain when compared to a standard waking state (Hobson, 1999). Neurobiological resemblance between REM sleep and another psychopathology, schizophrenia, was further detailed by Gottesmann (2006), who argued that natural REM sleep is a remarkable collection of schizophrenia endophenotypes. Several other authors took a somewhat more modest position and proposed that dreaming could serve as a restricted model of some aspects of psychopathologies rather than claiming an overall continuity between them. For instance, dreaming could serve to study the lack of involvement and emotion expression in schizophrenia (Hadjez et al., 2003), or several types of psychotic or neurological delusions that are common in dreams, such as age disorientation, paranoid experience of threats (Kelly, 1998), and delusional misidentifications, for example, mis- or hyper-identification of faces (Schwartz & Maquet, 2002).

Overall, there is very little consensus among researchers working on dreaming as to whether it can be treated as a model of wakefulness, and of what type of waking state: an intact consciousness or a psychotic mind. Furthermore, diverging views on the (dis)similarities between the waking and dreaming states result in the choice of different types of modelling relationships, for example, a global or a restricted modelling of waking consciousness if dreaming and wakefulness are regarded as similar (Revonsuo, 2006), and a modelling via negative analogy if they are regarded as dissimilar (Churchland, 1988).

6.6.2. *Original proposal*

Regarding proposals of using dreaming as a model of waking consciousness, which are often contradictory and even antagonistic (e.g., Hobson, 2001; Revonsuo, 2006), three types of problems were raised in *Study V*: (1) theoretical; (2) adequacy; and (3) practical feasibility concerns. Theoretical concerns deal with the concept of modelling and its representational relationship with the explanatory target. The strongest possible relationship is seen in the proposals of the global model of dreaming, some of which argue for the isomorphism, i.e., an identity between the model and its explanatory target, leaving little explanatory value in the modelling relationship. A more adequate relationship between a model and its explanatory target may be defined in terms of similarity, leaving dissimilar properties aside. Yet, the relevant degree of similarity is very difficult to define, as there is an infinite number of ways in which any two objects (or states of consciousness) can be similar or dissimilar (Wartofsky, 1979). Consequently, the relevant (dis)similarities have to be determined by researchers who may have different views regarding the key aspects of the mental states that can serve as a model, making the modelling relationship theory- and interest-dependent. For instance, the proposal for investigating dreaming as a model of natural waking consciousness presumes that dreaming is continuous with standard consciousness (Revonsuo, 2006). By contrast, the proposal of using dreaming as a model of pathological psychoses emphasizes neurophysiological and phenomenological dissimilarities between dreaming and standard waking states, and presumes continuity between dreaming and delirium tremens (Hobson, 1999, 2001).

Given that a widely accepted theory of dreaming is not yet in place, all uses of dreaming as a model of waking consciousness are naturally controversial. This raises a more general concern of whether it is adequate to use dreaming as a model of another conscious state when a scientific theory of dreaming itself is still limited, including its neural basis, function, and even definition (Windt, 2010). Arguably, scientific modelling can be successful only if a selected model is already well-understood, allowing the transfer of this knowledge to the understanding of the modelling target. Given that psychoses and waking consciousness are much more widely studied than dreaming, it is rather unlikely that a less researched dreaming can serve as a model of more explored states of consciousness. One may argue that this situation would rapidly change if more resources would be directed towards research of dreaming, however, a number of practical feasibility concerns raise doubt if a fast progress is likely to happen. A successful research model, such as the drosophila melanogaster model in genetics and biology (Arias, 2008), should provide large datasets in a relatively short time, observations and experimental manipulations with it should be relatively easy, and its running costs should be relatively low. Experimental research of dreaming seems to be an example of the opposite. Most notably, efficiency of data collection is very low, allowing for instance only four or five observations of REM sleep dreams during the whole night of recording, and even the more efficient ENSA paradigm enables to collect only about 10 NREM sleep reports in three hours (see *Study II*, Section 6.3), which is far from the efficiency of typical cognitive psychology paradigms that allow hundreds of observations (or trials) in a period of one hour or so (e.g., *Study VII*, Section 6.8). Furthermore, given that a neural marker of dreaming, such as P300 as a marker of conscious attention (Chennu et al., 2013), is unknown, the presence of dreaming can be observed only indirectly, through subjective reports that are affected by post-awakening amnesia, especially for schizophrenia patients (Okuma et al., 1970), making the dreaming model of psychosis particularly vulnerable to the mnemonic biases (see Sections 4.1 and 4.2). Manipulation with dream content, such as through a sensory stimulation at the sub-awakening threshold (e.g., Schredl et al., 2009) or through a transcranial direct current stimulation (tDCS) of cortex (as suggested in *Study VI*, see Section 6.7), is not always successful and often leads to somewhat unpredictable changes of dream content or even worse, to unintentional awakenings. Finally, laboratory research of dreaming requires long scanning hours and expensive personnel, partially explaining why there are so few neuroimaging studies of the neural mechanisms of dreaming.

Instead of a modelling relationship between dreaming and standard or abnormal waking states, which presumes a continuity between dreaming and waking consciousness, a more modest but also arguably a more promising approach is suggested in *Study V*, namely running a series of contrastive analyses studies (Baars, 1994) that would systematically compare dreaming and waking states. Contrary to the modelling approach, contrastive analyses do not rely on a unidirectional reasoning regarding relationship between two states under contrast, but instead, they systematically compare various possible similarities and dissimilarities between two contrasts. Instead of increasing the controversy between different proposals of dream modelling (Hobson, 2001; Revonsuo, 2006), contrastive analysis may be able to integrate diverging research lines by comparing dreaming with both standard waking state and pathological alterations of consciousness. In addition to a series of contrasts between dreaming and a passive standard or psychotic mentation (e.g., regarding self, cognitive bizarreness, metacognition, beliefs), a promising new endeavour may be analysis of (dis)similarities between dreaming (or lucid dreaming) and other natural, cognitively or pharmacologically induced ASCs, such as out-of-body experiences, hypnotic hallucinations or hallucinogenic psychomodulation. Arguably, contrastive analysis program may finally identify the most consistent similarities and dissimilarities between dreaming and waking states, which may also eventually lead to a restricted modelling program that would focus on a selected well-established contrast.

6.7. Study VI: New perspectives for the study of lucid dreaming: From brain stimulation to philosophical theories of self-consciousness (Noreika et al., 2010b)

6.7.1. *Literature review*

Cognitive deficiencies of REM sleep dreaming, such as a loss of rational thought, orientational instability and impaired self-reflection (Hobson et al., 2000; Kahn, 2007), are distinctive features of arguably the most intense natural ASC. It has been suggested that impaired dream cognition may be caused by hypoactivation of dorsolateral prefrontal cortex (DLPFC) during REM sleep (Hobson et al., 2000; Maquet et al., 2005; Muzur et al., 2002). However, not all of the REM sleep dreams are irrational (Meier, 1993). In particular, lucid dreaming is characterized by metacognitive insight into the hallucinatory nature of the dream state. It has been hypothesized that lucid dreaming is associated with a reactivation of DLPFC during REM sleep (Hobson et al., 2000; Kahn & Hobson, 2005), which was recently confirmed in an EEG/fMRI study by Dresler et al. (2012).

Lucid dreaming is thus dissimilar from both standard waking consciousness and typical REM sleep dreaming. In particular, perceptual experiences in lucid dreaming are hallucinatory unlike in wakefulness but similar to typical dreams, whereas cognitive abilities in lucid dreaming are much stronger than in non-lucid dreaming but somewhat similar to cognition in wakefulness. At the electrophysiological level of description, Voss et al. (2009) showed that lucid dreaming is associated with higher EEG gamma power over frontal regions when compared to non-lucid REM sleep dreams. When compared to waking state characterized by high alpha band coherence, lucid dreaming was found to have higher coherence in the delta and theta band spectrum. Following these observations, wakefulness, typical REM sleep dreaming, and lucid dreaming were suggested to be three sharply distinct states of consciousness (Hobson, 2009). However, differences between lucid and non-lucid dreaming may not be as sharp as previously suggested, but instead certain elements of dream lucidity may occur in non-lucid dreams (Windt, 2012; Windt & Metzinger, 2007), pointing to a gradual transition between different alterations of consciousness.

6.7.2. *Original proposal*

Even though lucid and non-lucid dreams seem to be very different with respect to their cognitive clarity, it is known that cognition in the form of speech and thought may occur in typical dreams (Kahn & Hobson, 2005; Meier, 1993), while lucid dreamers may sometimes lack full control of their actions and may show somewhat erratic reasoning (Brooks & Vogelsong, 1999; LaBerge & DeGracia, 2000). Arguably, there might be a slow gradation of different levels of cognition and insight from clearly non-lucid to the most intense lucid dreams. In particular, there seems to be a variety of the so called pre-lucid dreams, which are characterized by partial awareness of being in a dream (Brooks & Vogelsong, 1999). In the strongest sense of dream lucidity, it involves full cognitive clarity, including abilities to control the dream and to access autobiographical memory (Metzinger, 2009; Tart, 1988). This type of lucid dreams would be clearly different from the typical REM sleep dreams that have very limited and selective access to autobiographical memories (Windt & Metzinger, 2007). However, there may be many other types of dreams that are lucid in a weaker sense.

At least five different types of lucidity can be distinguished: attentional A-lucidity; behavioural B-lucidity; emotional E-lucidity; and cognitive C-lucidity; all of which together would form the full-scale F-lucidity (Windt & Metzinger, 2007). These distinctions are based on the availability of different types of information that reveal the virtual nature of a particular dream. A-lucidity takes place when a dreamer becomes capable of focusing their attention to the virtual fantasy-like aspects of dreaming. B-lucidity emerges when a dreamer gains a deliberate control over specific dream objects, characters or the whole dream plot, showing signs of lucid behaviour. E-lucidity is characterized by emotional reactions to dream events that would not be appropriate if these events would take place during wakefulness, but instead they are coherent given the virtual character of the dream. C-lucidity takes place when virtual reality of a dream becomes available to cognition and thought, and a dreamer begins to reason abstractly about the virtual nature of a dream. This type of lucidity forms the core of most of the definitions of lucid dreaming (Hobson, 2009; LaBerge & Gackenbach, 2000; Metzinger, 2009; Tart, 1988). Notably, A-, B- and E-lucidity types alone are not sufficient to form a convincing case of lucid dreaming; instead, they can be regarded as cases of pre-lucid dreams. Nevertheless, A-, B- and E-lucidity forms are required for the fully-fledged F-lucidity that would encompass all aspects of lucid dreaming.

Arguably, dream lucidity is a complex and graded phenomenon that ranges from isolated aspects of A-, B- or E- pre-lucid dreams to cognitively lucid dreams, in which a dreamer recognizes the virtual nature of a dream, to the full-scale lucidity with all aspects of mental functioning showing a coherent response to the internally generated dream events. Therefore, lucid dreaming is not sharply discontinuous from other types of dreaming, but instead its levels may fluctuate, i.e., increase or decrease, within a broader distribution of dream reports or even within a single dream. Thus, instead of dichotomous categorisation between lucid and non-lucid dreams, a more gradual measure could be applied to study lucid dreaming, such as the recently developed *Lucidity and Consciousness in Dreams scale* (LuCid; Voss et al., 2013). The use of such scales would allow studying certain aspects of dream lucidity in the more frequent typical or pre-lucid dreams. Furthermore, neural mechanisms of lucidity as a gradual measure could be studied by a parametric interference with the natural brain functioning during REM sleep, such as by applying tDCS over DLPFC. Hypothetically, such stimulation would alter dream lucidity, and controlled manipulation with either the intensity or the duration of tDCS would result into a changing degree of lucidity.

6.8. Study VII: Perception of short time scale intervals in a hypnotic virtuoso (Noreika et al., 2012)

6.8.1. *Methods*

Among non-pathological ASCs, changes in time processing, which is a fundamental dimension of the stream of consciousness (see Section 2.2.1), are most frequently studied in hypnosis. Typically, hypnotized individuals underestimate supra-second intervals when compared to the duration estimates obtained from the baseline waking state, which has been linked to the increased absorption and limited attentional resources for monitoring time-related cues (for a review, see Naish, 2007). However, none of the previous hypnosis studies has investigated possible changes in the sub-second interval range, which provides temporal axis for feature binding, and which can be analysed with the currently available cognitive models of time perception (e.g., Wearden, 1992). To study duration perception in this interval range, a case study (*Study VII*) was carried out with an experienced hypnosis virtuoso T.S.-H. (female, 43 years old), who has previously taken part in a number of hypnosis studies (Fingelkurts An. et al., 2007; Fingelkurts Al. et al., 2007; Kallio et al., 1999, 2005, 2011). T.S.-H. can experience vivid auditory and visual hallucinations under hypnosis, and she immediately responds to a posthypnotic suggestion of being hypnotized again without any standard induction procedures, which is associated with only exceptionally susceptible individuals. In the present study hypnosis was induced and cancelled by a single word, which was suggested during previous hypnosis sessions.

Two behavioural experiments of auditory duration perception were carried out within and outside hypnosis using Inquisit 3 program (Millisecond Software, 2008). During the repeated-standards temporal generalization experiment, the participant listened to pairs of tones (500 Hz) consisting of a standard tone (either 600 ms or 1000 ms) followed by a probe tone (for 600 ms standard: 300, 450, 600, 750, or 900 ms; for 1000 ms standard: 500, 750, 1000, 1250, or 1500 ms). The participant was instructed to report by pressing keyboard buttons whether the two tones were the same or not. During the time estimation task, the participant listened to different durations around 3 seconds (2100 ms, 2400 ms, 2700 ms, 3000 ms, 3300 ms, 3600 ms, and 3900 ms; all 500 Hz). After each stimulus the participant reported by a button press whether the sound was three seconds long or not.

6.8.2. *Results*

In temporal generalization experiment, baseline and hypnosis conditions differed when probes were compared to the 600 ms standard, but not when probes were compared to the 1000 ms standard. In particular, fewer ‘same’ responses were given under hypnosis than in the baseline condition when the 600 ms standard was compared to a 450 ms probe (χ^2=4.5, df=1, p<.05, Cramer's V=.24), whereas more ‘same’ responses were given under hypnosis than in the baseline condition when 600 ms standard was compared to a 750 ms probe (χ^2=6.3, df=1, p<.05, Cramer's V=.28). Temporal generalization was inspected further by plotting the counts of ‘same’ responses against the probe duration divided by the standard duration in the 600 ms and 1000 ms conditions, separately for hypnosis and baseline states of consciousness. Temporal generalization gradients, i.e., functions representing 600 ms and 1000 ms conditions, did not superimpose well in the baseline state, suggesting violation of the scalar property of timing in a sub-second-to-second scale. On the contrary, temporal generalization gradients superimposed well under hypnosis, indicating more orderly interval timing in hypnosis than in the baseline waking state. Modelling of behavioural responses suggested that T.S.-H. had higher sensitivity to the sub-second intervals in hypnosis than in the baseline waking state. In addition, the distortion parameter showed the opposite memory bias for the 600 ms standard in the two states of consciousness: underestimation of standard in the baseline state, and overestimation of standard in hypnosis.

In the time estimation experiment, responses indicating ‘3-second’ judgement peaked at 2100 ms in the baseline condition and at 2700 ms under hypnosis. These findings replicate earlier reports showing that supra-second intervals are underestimated in hypnosis when compared to the baseline waking state (e.g., Naish, 2001). It seems that hypnosis facilitated sub-second and inhibited supra-second perception, providing further support to a theory of two distinct timing systems in the brain (Lewis & Miall, 2003).

6.9. Study VIII: Variability of duration perception: From natural and induced alterations to psychiatric disorders (Noreika et al., 2014)

6.9.1. *Literature review*

One of the most distinctive cognitive distortions, which may open up new possibilities for studying ASCs, is the change of perceived duration, as for instance reported by a hospitalized psychiatric patient: 'I can't estimate time. […] I noticed my watch was accelerated... […] The time you keep here isn't Greenwich time' (Lewis, 1932, p. 617–618). Distorted perception of duration has been reported in many pathological ASCs, including stimulant dependence (Wittmann et al., 2007), mania (Bschor et al., 2004), borderline personality disorder (Berlin et al., 2005), and most notably, schizophrenia (Carroll et al., 2008) and depression (Gil & Droit-Volet, 2009). Patients with schizophrenia tend to overestimate intervals as if the subjective time is going faster for them (Densen, 1977; Johnson & Petzel, 1971; Tysk, 1983a, 1983b; Wahl & Sieg, 1980), while patients with depression tend to underestimate durations (Gil & Droit-Volet, 2009), although, these findings are not always replicated (for schizophrenia, see Carroll et al., 2008; for depression, see Bschor et al., 2004). Time perception may also change in non-pathological ASCs, such as dreaming (Moiseeva, 1975) or LSD psychomodulation (Aronson et al., 1959). Likewise, research of duration perception under hypnosis reveals very consistent findings of underestimation of temporal intervals (Bowers, 1979; Naish, 2001; Noreika et al., 2012 (*Study VII*, Section 6.8); St. Jean & MacLeod, 1983; for a review, see Naish, 2007).

Notably, changes in perceived duration are not limited to alterations of consciousness. Contrary to this, they seem to be rather frequent, albeit less intense and somewhat unnoticed, in normal waking life. In has been shown in numerous studies that perception of duration changes depending on such diverse natural factors as: emotions (Angrilli et al., 1997; Gil et al., 2007), physical properties of stimuli (Wearden et al., 1998; Xuan et al., 2007), environmental effects of light (Aschoff & Daan, 1997; Morita et al., 2007), colour (Humphrey & Keeble, 1977), space (Collett, 1974), and menstrual (Montgomery, 1979; Morofushi et al., 2001) or circadian (Aritake-Okada et al., 2009; Kuriyama et al. 2005) cycles. For instance, Nakajima et al. (1998) instructed participants to sit on a chair for a period of 36 hours (this is not a typo!), and each second hour participants were asked to produce 10 s and 60 s intervals. The produced durations were the longest early in the morning, revealing a circadian modulation of time perception.

Numerous reports of cognitive instability of duration perception demonstrate the enormous flexibility of time processing mechanisms. Interestingly, behaviourally very similar if not identical changes of duration perception can be observed in various waking life situations and naturally occurring, cognitively or pharmacologically induced and pathological ASC, such as a comparable underestimation of duration in depression (Gil & Droit-Volet, 2009) and hypnosis (Naish, 2001). What are the underlying causes of such distortions of duration perception, and would understanding them partially explain the relationship between different states of consciousness? Do behavioural similarities in duration perception imply that healthy individuals may occasionally undergo pathological abnormalities of duration perception, which can be otherwise observed in patients with neuropsychiatric disorders? Would it be possible to regard artificially induced changes of duration perception as a model of pathological alterations of time? To address these questions, a formal model of intra- and inter-individual distortions of duration perception was developed in *Study VIII*.

6.9.2. *Original proposal*

It was proposed in *Study VIII* that duration perception is a multifactorial function unifying a large number of externally (e.g., spatial properties of the environment) and internally (e.g., phase of menstrual cycle) driven factors. Thus, a perceived duration $D_{perceived}$ depends on the physical duration $D_{physical}$ and a number n of modulating factors x_i whose effects can be mathematically described by functions f_i. Thus, $D_{perceived}$ can be regarded as a product of $D_{physical}$ and all relevant functions f_n:

$$D_{perceived} = D_{physical} \cdot f_1(x_1) \cdot \ldots \cdot f_n(x_n)$$

Each function f_i has its own range of possible values, e.g., f_1 may have a range of [0.6–0.9], while f_2 may have a range of [1.1–1.5]. Function values < 1 shorten $D_{perceived}$ and function values > 1 lengthen $D_{perceived}$, e.g., f_1 with a range of [0.6–0.9] will result in the shorter $D_{perceived}$ than $D_{physical}$. Distinct factors may also cancel each other's effects, e.g., if a value of $f_1(x_1)$ is 1.25 and the value of $f_2(x_2)$ is 0.8, and all other functions have a value of 1, then $D_{physical}$ of 10 sec yields a precise $D_{perceived}$:

$$D_{perceived} = D_{physical} \cdot f_1(x_1) \cdot f_2(x_2) \cdot \ldots \cdot f_n(x_n) = 10 \cdot 1.25 \cdot 0.8 \cdot 1 \cdot \ldots \cdot 1 = 10 \text{ (sec)}$$

Furthermore, factors capable of modulating duration perception can either be independent or form clusters of mutually dependent factors. For instance, Kuriyama et al. (2005) demonstrated that a fluctuation of produced intervals over a 30-hour period correlates with the core body temperature, suggesting that the circadian and temperature factors are associated. Contrary to this, factor of colour (Humphrey & Keeble, 1977) might be independent of the circadian and temperature factors:

$$D_{perceived} = D_{physical} \cdot f_{color}(x_{red}) \cdot \ldots \cdot f_n(x_n) \cdot f_{cycle}(x_{circadian}, x_{temperature}) \cdot \ldots \cdot f_m(x_m, y_m, \ldots)$$

Regarding the occurrence of distortions of duration perception, there are several routes of how functions can modulate $D_{perceived}$. First, $D_{perceived}$ differences between the standard and pathological states of consciousness might be related to the ordinary variability in duration processing, defined by the width of a possible range of function values. For instance, f_1 with a range of [0.5–1.5] in a healthy person might correspond to f_1 with a range of [0.5–1.1] in a depressed patient and a range of [0.9–1.5] in a psychotic patient. In line with these formal possibilities, Morofushi et al. (2001) reported that healthy women produced longer durations at 20:00 in the early luteal phase and at 08:00, 14:00, and 20:00 in the follicular phase of the menstrual cycle, when compared to other phases of the circadian and menstrual cycles. On the contrary, no within-participant variation of $D_{perceived}$ was observed in women with premenstrual syndrome, suggesting that a range of function values may have been narrowed in the premenstrual syndrome group. The range of function values may also broaden, e.g., from [0.5–1.5] to [0.2–1.6], or shift, e.g., from [0.5–1.5] to [0.4–1.4], between different states of consciousness or under different naturalistic conditions.

Another possible route for the occurrence of $D_{perceived}$ distortions is the involvement of different modulating factors. Factor reduction would take place if some of the functions modulating duration perception in one ASC would show a value of 1 in another state of brain/mind. Likewise, factor increase would take place if a factor with a value of 1 in one state would change its value in another state of consciousness. Obviously, a difference between factor reduction and factor increase is relative and depends on which state of consciousness is regarded as a baseline. Arguably, when a standard waking state is compared to a non-pathological or pathological ASC, the first one should be regarded as the baseline for a contrast between the states. More conceptual complications emerge when several ASCs are compared, in which case the baseline choice may depend on the research pragmatics, for example, the more investigated state could be regarded as a baseline state for another ASC.

Assuming that behavioural associations of $D_{perceived}$ between pathological and non-pathological ASCs are functionally grounded, an intriguing possibility is to model $D_{perceived}$ distortions in psychiatric disorders (e.g., depression) by means of inducing alterations of consciousness (e.g., hypnosis) in healthy individuals. However, conceptual analysis of the $D_{perceived}$ model shows that cognitive similarities between the naturally occurring, induced and pathological ASCs do not necessarily imply the same underlying functions and/or their values. Thus, convincing modeling of pathological distortions of $D_{perceived}$ by studying healthy participants in non-pathological states of consciousness requires more direct evidence that the underlying variability sources are the same in both states of consciousness. Future studies should focus on the development of tools to identify different causes of $D_{perceived}$ variability. For instance, a broadening or a narrowing of the range of function values could be inferred from the respective increases or decreases in variation coefficients, e.g., intra-individual standard deviation of $D_{perceived}$ scores. A shift of the range could be suspected from changes in the central tendency, e.g., mean of $D_{perceived}$. Factor reduction or increase could be inferred from significant group x factor interactions, when certain factors show an impact on $D_{perceived}$ in one group only. Until such studies are carried out, despite some intriguing similarities between duration perception in different alterations of consciousness, possibilities for their modeling relationship remain largely speculative.

7. DISCUSSION

The main aims of this dissertation were to advance theory of how different alterations of consciousness are related, and to propose new efficient experimental paradigms for studying subjective experiences and their changes in ASCs. The results were published in eight studies, four empirical (*Studies I–III, VII*, see Sections 6.2–6.4, 6.8) and four theoretical (*Studies IV–VI, VIII*, see Sections 6.5–6.7, 6.9). While theoretical studies focused largely on dreaming (*Studies IV–VI*, see Sections 6.5–6.7), which is the most common paradigmatic ASC, each of the empirical studies investigated subjective experiences and/or cognitive processes in different types of ASCs: naturally occurring dreaming (*Study II*, see Section 6.3), cognitively induced hypnosis (*Study VII*, see Section 6.8), pharmacologically induced sedation (*Study I*, see Section 6.2), and pathological alteration of consciousness in schizophrenia (*Study III*, see Section 6.4).

It was found that phenomenal consciousness does not necessarily diminish in unresponsive states of consciousness. In particular, research participants reported having had subjective experiences in more than 50% of unresponsive sedation sessions (*Study I*, see Section 6.2). Likewise, minimal static dreams were reported in about 30% of the early night NREM sleep awakenings (*Study II*, see Section 6.3). In *Studies I* and *II*, new methods were successfully introduced for the content analysis of subjective reports, namely the *Orlinsky's Modified Scale for Perceptual Complexity of Dreams* (O-PC-Dreams) and the *Subjective Experiences during Anaesthesia Coding System* (SEDA-Coding). A further methodological advancement was the application of a new early-night serial awakenings (ENSA) paradigm, which enabled the collection of a large number of dream reports in a relatively short time (*Study II*, see Section 6.3). It was also suggested that lucid dreaming, which is one of the most complicated ASCs to investigate due to its infrequency, could be studied by analysing different aspects of lucidity in the so-called pre-lucid dreams (*Study VI*, see Section 6.7). Content analysis of dreams of psychotic patients indicated higher bizarreness level when compared to dreams of healthy controls (*Study III*, see Section 6.4). Blind judges were not able to distinguish above chance level patients' dream and waking mentation reports, indicating a close phenomenological resemblance between psychotic dreaming and wakefulness (*Study III*, see Section 6.4). Yet, causal relationship between these states of consciousness remains uncertain. It was argued that dreaming may modulate subjective contents of waking consciousness, or likewise that waking consciousness may modulate dream experiences, or that these states of consciousness may be independent (*Study IV*, see Section 6.5). Regarding more ambitious suggestions to treat dreaming as a model of waking consciousness, a number of theoretical, adequacy and practical feasibility issues were raised, indicating that such suggestions are not likely to develop into influential research programs (*Study V*, see Section 6.6). Instead, more modest contrastive analyses were suggested between different states of consciousness, comparing their phenomenology, cognitive processes and neural mechanisms. Behavioural analysis and modelling of time perception in a hypnotic virtuoso found a more consistent perceptual timing under hypnosis than in the waking state (*Study VII*, see Section 6.8). Theoretical analyses of time perception studies led to the proposal of a new framework of how time distortions in different ASCs and natural fluctuations might be cognitively related, but have diverse underlying causes and mechanisms (*Study VIII*, see Section 6.9). In the following sections, the most important findings are discussed in more detail, placing them in a context of contemporary research of ASCs.

7.1. Methodological advancements

To map subjective experiences in unresponsive states of consciousness, two scoring systems were developed for the content analysis of subjective post-alteration reports: the SEDA-Coding (*Study I*, see Section 6.2) and the O-PC-Dreams (*Study II*, see Section 6.3). The SEDA-Coding was designed with the aim to assess the presence of different types of subjective qualities (e.g., the presence of visual consciousness) rather than the exact contents of consciousness (e.g., experience of individual visual images). The SEDA-Coding identifies different types of micro-level (e.g., auditory, sensorimotor sensations) and macro-level experiences (e.g., dream-like, out of body experiences). Micro-level experiences are atomistic and cannot be subdivided into further modalities, whereas macro-level experiences consist of micro-level experiences that may or may not form more complex macro-forms of consciousness. Compared to other available instruments for classification of intraoperative experiences (e.g., Mashour et al., 2010), the SEDA-Coding includes additional categories that clinically might be less relevant, for example, visual experiences or time perception, but may have fundamental importance for the experimental research of phenomenal consciousness during sedation and anaesthesia. Instead of focusing on different modalities of experiences, the O-PC-Dreams of *Study II* was designed with an aim to scale subjective dream reports according to their overall perceptual complexity, with score 1 referring to a single isolated experience and score 7 referring to the most complex sets of experiences within changing hallucinatory sceneries. Compared to the original version of *Orlinsky's Sleep Mentation Scale* (Farthing, 1992; Orlinsky, 1962), the O-PC-Dreams omitted the category of white dreaming because of its uncertain status, i.e. given that the contents of white dreaming are unknown, they cannot be correctly placed on the scale. Both of the developed content analysis methods proved to be reliable and yielded strong inter-judge agreement (*Studies I*, *II*, see Sections 6.2, 6.3). They also proved to be empirically meaningful and helped to identify important aspects of subjective experiences in unresponsive states, for example, the relatively high frequency of subjective experiences under dexmedetomidine sedation (*Study I*, see Section 6.2), and the predominantly static nature of the early night NREM sleep dreaming (*Study II*, see Section 6.3).

As an alternative to the use of formalized content analyses systems, which may be sensitive in identifying specific experiences under interest but may also miss other important aspects of conscious experiences, an unguided analysis was carried out when comparing sleep and waking mentation reports in *Study III* (see Section 6.3). Four independent blind judges were instructed to read the subjective reports and rate their origin (dreaming/waking) and reporter (schizophrenia patient/healthy control). Thus, instead of focusing on specific aspects of reports, judges rated the overall content of subjective experiences. This approach appeared to be successful and yielded significant results: while judges had no difficulties in differentiating between waking and dream reports of a control group, they could not distinguish above chance level reports of psychotic schizophrenia patients, suggesting a strong phenomenological similarity between dreaming and waking psychosis (see also Hadjez, 2003; Hobson, 2001; Skrzypińska & Szmigielska, 2013). Arguably, unguided classification of subjective experiences into pre-determined dichotomous categories, such as waking/dreaming or patient/control (see Study *III*, see Section 6.4), might be a simple but efficient method to treat the first-person data in neurophenomenological research (Lutz & Thompson, 2003; Varela, 1996).

Research of ASCs requires establishment of a baseline state of consciousness, yet it is not always self-evident which state should be taken as a baseline condition for a particular alteration of consciousness. In the present dissertation, experimental feasibility of different contrast conditions was tested for three classical ASCs, hypnosis (*Study VII*, see Section 6.8), sedation (*Study I*, see Section 6.2) and dreaming (*Study II*, see Section 6.3). In hypnosis studies, perceptual or cognitive changes are often tested by giving suggestions that are expected to alter the brain function of interest (e.g., Mazzoni et al., 2009). It is usually expected that a contrast between cognitive or behavioural responses to the suggestions given in and out of hypnosis will reveal the underlying neurocognitive mechanisms of hypnotic suggestibility. Yet, even though such comparisons may reveal mechanisms of specific experiences under hypnosis, they are limited in revealing the neural mechanisms of a hypnotic state itself (Kallio & Revonsuo, 2003). Instead, a more promising contrast might be between a waking state of consciousness and a pure hypnotic state when no suggestions are given, which is sometimes called neutral hypnosis (Kallio & Revonsuo, 2003; Naish, 2007). In *Study VII* (see Section 6.8), such contrast was carried out in a single participant, hypnosis virtuoso T.S.-H., who has previously taken part in a series of EEG studies (Fingelkurts Al. et al., 2007; Fingelkurts An. et al., 2007; Kallio et al., 1999), serving as an efficient case model to study neural mechanisms of neutral hypnosis. However, it was not tested in previous studies if T.S.-H. is capable of carrying out long lasting, cognitively demanding behavioural tasks in a deep hypnotic state. In *Study VII*, the neutral hypnosis-induced changes in perception of sub-second intervals were reliably detected in a single participant when waking and hypnotic states were relatively rapidly switched, avoiding prolonged periods of hypnotic induction and recovery. Interestingly, T.S.-H. improved her time perception in hypnosis, pointing out that behavioural tasks for studying highly susceptible individuals should be programmed to avoid ceiling effects, as performance accuracy might significantly increase during hypnosis.

The choice of contrast conditions is particularly complicated when studying unresponsive states, as the confound of forgetting cannot be avoided when subjective reports are collected after regaining of responsiveness. In this dissertation, subjective experiences under sedation were successfully analysed by contrasting the effects of different anaesthetic/sedative agents. For instance, the frequency of laboratory-related experiences was found to be higher during sevoflurane compared to dexmedetomidine sedation (*Study I*, see Section 6.2). These findings suggest that there is no single route of transition from relaxed waking to unconscious anaesthesia, and that administration of different anaesthetic agents brings out different rates or types of subjective experiences until consciousness is lost. Another possible comparison condition for an unresponsive alteration of consciousness may be an unconscious state; arguably, contrasting them may reveal the neural correlates of consciousness (Revonsuo, 2006). In *Study II* (see Section 6.3), NREM sleep stage 3 was identified as the most suitable awakening time for experiments aiming to contrast similar proportions of dream and dreamless periods of sleep when the sleep stage is kept constant. Notably, it is particularly important to control the sleep stage in studies aiming to identify the neural correlates of dreaming, because the frequently performed contrast between REM sleep dreaming and NREM dreamless sleep (e.g., Massimini et al., 2010) may turn out to be a hardly interpretable comparison of different sleep stages which vary in many different cognitive or neurophysiological functions.

While it is feasible to carry out case studies aiming to identify perceptual or cognitive changes during alterations of consciousness (*Study VII*, see Section 6.8), larger participant samples are necessary in order to draw more general conclusions. Unfortunately, practical constraints often limit data collection from large groups of participants undergoing natural or induced ASCs, which is particularly problematic in dream research (*Study V*, see Section 6.6). To increase efficiency of collection of dream reports in the sleep laboratory, a novel ENSA paradigm was tested in *Study II* (see Section 6.3). Continuous interruption of the natural development of sleep cycles proved to be an efficient way of collecting NREM sleep reports, yielding on average eight reports in three hours while maintaining the stable profile of pre-awakening EEG spectral power. Given that NREM sleep dreams appeared to be perceptually simple and static, the ENSA paradigm is suitable for studying minimal forms of consciousness. A recent extension of serial awakenings to the whole night recording can be applied to study more complex REM sleep dreams (Siclari et al., 2013).

7.2. Theoretical advancements

While the field of consciousness studies, especially visual awareness research, is dominated by experiments on specific isolated contents of consciousness (e.g., Koivisto & Revonsuo, 2010), an alternative approach to focus on the totality of subjective experiences in different states of consciousness may provide new perspectives for studying subjectivity. In particular, research of the overall stream of subjective experiences and their changes may reveal the global properties and internal structure of consciousness, which are not necessarily observable when focusing on a single isolated experience in standard behavioural experiments. For instance, *Study II* (see Section 6.3) showed that minimal forms of consciousness exist during early night NREM sleep: awakened participants reported seeing static visual images, suggesting that a broad perceptual or semantic context and temporal dynamics are not necessary for a conscious experience to arise. It seems that the stream of consciousness can stop developing; yet, conscious experiences do not necessarily cease. Furthermore, a follow-up study showed that the experience of time can arise irrespective of the absence of temporal changes of experiences, as research participants often rated their static dreams to last for 30 s, 1 min and even longer (Noreika et al., 2010c). These observations indicate that subjective experiences maintain the temporal structure even in the most minimal static forms of dreams, confirming that temporality, i.e., extension in time, is a fundamental property of phenomenal consciousness (see Section 2.2.1).

It has been suggested that dreaming, the most common and paradigmatic ASC, could be treated as a research model of other states consciousness (Hobson, 2001; Revonsuo, 2006). However, *Study V* (see Section 6.6) suggests that even though many perceptual and cognitive processes are similar between dreaming and psychosis (*Studies III*, *IV*, see Sections 6.4, 6.5) or between dreaming and standard waking consciousness (Revonsuo, 2006), proposals to use dreaming as a research model of consciousness are not currently achievable due to theoretical, adequacy and practical feasibility limitations. Instead, the more modest phenomenological and neurophysiological contrasts between different alterations of consciousness are more likely to reveal the neurocognitive mechanisms shared by different ASCs. For instance, comparison of the overall stream of experiences in schizophrenia patients and healthy individuals showed that in some cases the psychotic and the dreaming minds might be indistinguishable (*Study III*, see Section 6.4). This finding points to the clinical importance of systematic contrasts between different states of consciousness. In particular, schizophrenia patients may experience similar delusions in their waking life and dreaming, although this does not seem to hold for each type of delusion (D'Agostino et al., 2013), showing simultaneous continuity and discontinuity between psychotic waking and dreaming states of consciousness (*Study IV*, see Section 6.5).

Two different types of contrasts between ASCs were considered in *Studies I–VIII*: a classical sharp contrast and a gradual or transitional contrast. A sharp contrast compares an overall ASC and a baseline waking state of consciousness (*Studies III*, *VII*, see Sections 6.4, 6.8), or several different alterations of consciousness (*Studies I–III*, see Sections 6.2–6.4), which is a standard approach in most of the contemporary studies of ASCs. A gradual contrast, suggested in *Study VI* (see Section 6.7), however, systematically maps different degrees of alteration, for example, the increasing levels of lucidity in dreams, which may be a more sensitive approach for detecting mild distortions of consciousness than a sharp contrast. In particular, a gradual contrast might be able to identify temporal dynamics of changing perceptual and cognitive functions in the transition from one to another state of consciousness.

As an alternative to the content analysis of subjective reports, different states of consciousness can be tested using the same behavioural paradigms and cognitive modelling (*Studies VII*, *VIII*, see Sections 6.8, 6.9). In this type of contrasting, a particular promising domain is perception of time. Given that temporal binding is the core of the stream of consciousness (Dainton, 2006), temporal distortions are very common in natural, induced or pathological alterations of consciousness (*Study VIII*, see Section 6.9). Arguably, a systematic comparison of such temporal distortions may reveal shared cognitive processes of different states of consciousness.

Unfortunately, despite the methodological advancements of the content analysis methods, reportability and cooperativeness constraints remain major obstacles for drawing decisive inferences about the presence or absence of consciousness. Furthermore, even if a conscious agent is cooperative and willing to report all experiences, some of them may not be available for conscious access due to phenomenological overflow of cognitive accessibility (Block, 1995, 2007, 2011, see also Sections 2.5.4 and 4.1). In cases when the contents of phenomenal consciousness emerge but are not available for access consciousness (Block, 1995), the trap of reportability leaves no room for a certainty in the assessment of subjective states. Arguably, it may remain impossible to distinguish a genuine dreamless sleep from sleep with forgotten dreaming until a necessary and sufficient neural correlate of phenomenal consciousness is determined, in which case the stream of consciousness would be assessed by the neural activity measures.

7.3. The future perspectives for studying alterations of consciousness

It is expected that future studies of ASCs, while continuing the development of the first-person data analyses, will focus on the neural mechanisms of spontaneously generated subjective experiences and their distortions. However, instead of correlative EEG or fMRI designs that dominate in the contemporary neuroimaging of ASCs, experimental paradigms enabling causal interference with the spontaneous neural functioning, such as by non-invasive brain stimulation methods TMS or tDCS (as suggested in *Study VI*, see Section 6.7), will become more popular. The first attempts to apply tDCS for studying the neural mechanisms of dreaming during REM sleep confirmed homology of brain regions supporting the same type of subjective experiences and brain functions in waking and dreaming: tDCS over prefrontal regions was associated with increased cognitive insight and lucidity in dreams (Stumbrys et al., 2013), stimulation of visual cortex induced higher rates of dreamed visual experiences (Jakobson et al., 2012), whereas inhibitory stimulation of sensorimotor cortex reduced the frequency of dreams with motor activity (Noreika et al., in preparation). Such studies may eventually indicate which brain regions, through their excitation or inhibition, lead to various distortions of subjective experiences in ASCs.

When combined with EEG or local field potential measurements, brain stimulation studies may also reveal what consequences the altered processing in these regions have for the consciousness-related electrodynamics of the widespread cortical networks. Recently, Casali and colleagues (2013) applied TMS pulses over different cortical regions during different states of consciousness, and measured complexity of widespread EEG responses to the TMS perturbation of spontaneous cortical activity. They found that perturbational complexity index (PCI) of information integration and differentiation in EEG signal, derived from the information integration theory of consciousness (Tononi, 2010, 2012, see Section 2.5.5) successfully distinguished different levels of consciousness in sedation, sleep and traumatic brain injury. Development of consciousness science in recent years suggests that information integration account of consciousness (Tononi, 2010, 2012) may become the most dominant neurocognitive theory of consciousness, even though it is not entirely compatible with the strong version of biological realism (see Sections 2.4.3 and 2.5.5). However, the current version of PCI does not seem to detect the essential theory-driven features of consciousness. In particular, PCI does not differ between the ‘eyes closed’ and ‘eyes open’ conditions in standard waking state (Casali et al., 2013), ignoring differentiation or phenomenal diversity of consciousness. Further developments of PCI and other similar EEG indexes should aim to be more sensitive to alterations in both states and contents of consciousness.

Neuroimaging studies aiming to contrast dreaming and dreamless sleep as conscious and unconscious states of mind, as suggested in *Study II* (see Section 6.3), will need to develop empirical arguments for rejection (or acceptance) of a possibility that dreamless sleep is forgotten dreaming and thus, a conscious state (Schredl et al., 2013). An ultimate test of it would be to check if neural correlates of dreaming, but not of active memory formation or working memory updating in response to the stream of internally generated experiences, are present during dreamless sleep, which would indicate the presence of dreaming, but absence of its recall. However, as long as the neural markers of dreaming or working memory during sleep are unknown, the status of dreamless sleep could be investigated indirectly, for example, by studying neural mechanisms underlying white dreaming, when awakened participants have a feeling that they were dreaming, but cannot remember any further details about it. White dreaming is surprisingly frequent: participants report it when explicitly asked in about 40% of early night awakenings from NREM sleep stages 2 and 3 (*Study II*, see Section 6.3). White dreaming is also present, but to lesser extent, in sedation reports (*Study I*, see Section 6.2). Arguably, systematic contrasts between white dreaming and dreamless sleep as well as between white dreaming and recalled dreams may reveal whether white dreaming is more similar to dreams or dreamless sleep, eventually developing paradigms to map active memory updating while dreaming, such as those used to study waking memory consolidation and reactivation during sleep (Diekelmann et al., 2009; Schönauer et al., 2014). Recently, Eichenlaub et al. (2014) introduced a novel approach for studying the neural basis of dream recall and its failure: high and low dream recallers were compared using a passive auditory oddball paradigm during both wakefulness and sleep. High recallers showed higher P3a evoked EEG potentials to rare sounds, indicating a more efficient attention orientation to novel sensory information. Interestingly, the same ERP differences between the high and low dream recallers were observed during NREM sleep, suggesting that more efficient attentional processing is maintained during sleep, which may eventually lead to higher recall of dreamed perceptual experiences. Finally, carefully designed studies of behavioural training of dream recall in the sleep laboratory, such as presentation of sensory memory cues of possible dream content or enhancement of rapid orientation after awakening, may increase dream recall at the cost of decreasing white dreaming or even dreamless sleep. Such training would reduce the rate of misjudgements of recall categories and would improve the quality of a neuroimaging contrast between dreaming and dreamless sleep.

Interactions between different states of consciousness should also be studied using a gradual parametric approach, such as in the transition from non-lucid to pre-lucid to fully-lucid dreams (*Study VI*, see Section 6.7), or between dreams of increasing perceptual complexity (*Study II*, see Section 6.3). Perhaps one of the easiest transitions of conscious states to study and manipulate experimentally takes place during sleep onset, when cognitive functions and conscious experiences undergo changes from alert to relaxed to drowsy to unresponsive states of mind (Goupil & Bekinschtein, 2011). Recently, it was demonstrated that auditory perception undergoes spatial distortion in the drowsy state of consciousness, and healthy individuals begin showing neglect-like misjudgments regarding sounds coming from the right side of their perceptual space (Bareham et al., submitted). Given that space perception is closely associated with time perception and processing of other magnitudes (Fabbri et al., 2012; Walsh, 2003), it is likely that the latter would also be affected by the increasing sleepiness. Tracing down changes in these and other cognitive functions as well as the underlying neural processes may eventually reveal how an ASC emerges and develops in time. Some of the perceptual and cognitive changes might be unique for specific ASCs, such as susceptibility to external influences in hypnosis, whereas some other distortions seem to be shared by different ASCs, such as changes in time perception, observed in hypnosis, LSD psychomodulation, depression, schizophrenia (*Studies VII*, *VIII*, see Sections 6.8, 6.9), as well as several other mental disorders, including attention-deficit/hyperactivity disorder (Noreika et al., 2013) and autism spectrum disorders (Falter et al., 2012). Arguably, continuing research of ASCs will lead to better understanding, if not research models (*Study V*, see Section 6.6), of regular waking consciousness and cognition in some of these pathologies. Likewise, several recent studies began to investigate interactions between ASCs and baseline waking states, which seem to share the same psychological and neural traits, such as increased attentional waking ability in frequent lucid dreamers (Blagrove et al., 2010) and high dream recallers (Eichenlaub et al., 2014, see also Ruby et al., 2013), or reduced amygdala volume in participants prone to bizarre dreaming (De Gennaro et al., 2011). Future studies may find that a relationship between an ASC and a standard waking state is bidirectional with both of them having the capability to influence each other (*Study IV*, see Section 6.5).

8. CONCLUSIONS

1. Phenomenal consciousness is dissociable from responsiveness, as subjective experiences do occur in unresponsive states of mind, including sedation (*Study I*, see Section 6.2) and sleep (*Study II*, see Section 6.3).

2. Efficiency of laboratory research of alterations of consciousness can be increased by serially interrupting NREM sleep (*Study II*, see Section 6.3), or by studying selected individuals who show extremely strong forms of an ASC, such as hypnotic virtuosos (*Study VII*, see Section 6.8).

3. Strong inter-judge agreement can be achieved using both guided (*Studies I*, *II*, see Sections 6.2, 6.3) and unguided (*Study III*, see Section 6.4) analyses of subjective reports, confirming empirical reliability of phenomenological analysis of alterations of consciousness. Relatively rare ASCs, such as lucid dreaming, might be better studied by a gradual contrast of subjective changes (*Study IV*, see Section 6.5).

4. Content-wise, dreaming and waking mentation reports collected from psychotic patients can be indistinguishable for blind judges (*Study III*, see Section 6.4), indicating a close resemblance of these states of consciousness.

5. Despite phenomenological similarities, dreaming should not be treated as a uniform research model of psychotic or intact stream of consciousness (*Study V*, see Section 6.6). On the contrary, there seems to be a multiplicity of routes of how different states of consciousness, such as dreaming and psychosis, can be associated (*Study IV*, see Section 6.5).

6. Time perception distortions observed in hypnosis (*Study VII*, see Section 6.8) are also common in other alterations of consciousness (*Study VIII*, see Section 6.9). Yet, despite cognitive similarity, the mechanisms of such temporal changes might be different and cognitive modelling-driven comparative research is needed in order to identify the underlying routes of time distortions in different states of consciousness (*Study VIII*, see Section 6.9).

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