The EEG Slow Wave Activity; a possible marker for consciousness

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Abstract

The nature of consciousness, is an age-old question engaged human being by questioning the sense of him'self'. From a modern scientific perspective, consciousness is thought to arise from the neuronal activity of the brain which can be considered to exist in a wide variety of states associated with unique neural signatures, behavioral states, etc. Among such neural states are sleep, coma, and anesthesia, states in which it is argued that we are unconscious (i.e. we do not experience anything). Investigating the neural signatures of such states can lead to greater understanding of how the brain can give rise to the phenomena of consciousness.

The aim of this thesis is to investigate the dissociation between conscious and unconscious states, specifically by measuring alterations in slow wave activity (SWA) in the Elecetroencephalogram (EEG), in the presence and absence of a subjective dream experience during deep sleep.

For that purpose, we recruited healthy subjects that were sleep deprived for one night and subsequently recorded with EEG during morning sleep. An intermittent awakening paradigm was then performed during NREM sleep stages, to collect dream reports. SWA was calculated as mean power in the delta band frequency, based on the last 20 seconds of EEG prior to awakening.

Statistical analysis of our EEG data showed no significant difference in SWA between having and not having a subjective experience prior to being woken up. While the results can be confounded by circadian rhythms, noisy recording environment, and other factors, we suggest that SWA alone is not sufficient to separate dreams from non-dreams in NREM sleep.

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1 Introduction

What does it mean to be conscious? The intrinsic awareness of being, experiencing life, the joy of dancing, the sweetness of the chocolate ice-cream, the excitement of skydiving, the delightfulness of a kiss, or the stream of thoughts as the voice inside the head, all are manifestations of what is called consciousness. What is it? Is it something specific to humans? Despite of many unknowns, almost everyone agrees on the fact that "consciousness" exist, yet there is neither a consistent definition nor a fundamental explanation for this phenomenon. We might not be able to explain consciousness for now, but it is assumed that consciousness is correlated with brain activity. That is why the study of neural correlates of consciousness is a rising topic in science these days (Miller, 2005; Storm, et al., 2017; K.Seth, 2018).

1.1 Consciousness

The human brain is one of the most complex systems we know, consciousness on the other hand, appears to be an even more complex phenomenon assumed to be driven from the brain. "That I am conscious here and now is the one fact I am absolutely certain of, all the rest is conjecture" (Tononi & Koch, 2015). The questions regarding the conscious phenomenon are divided into two main categories by David Chalmers, the 'easy' and the 'hard' problems of consciousness (Chalmers, 1996). Easy questions are mostly "how" questions, e.g., how does the brain process the signals coming from the outside world to make a conscious experience? While the hard problem concerns "why", that in Chalmers's own words is: "why is all the processing accompanied by an experienced inner life?" (Chalmers, 1996). To be able to answer those questions and to draw intellectual theories about this intangible phenomenon, a scientific point of view is needed.

There is a controversial point of view, in which the nature of being, as well as the content of consciousness such as, thoughts, beliefs, percepts, sensations, memories, emotions and sense of agency are all assumed to be generated from unconscious processes (Oakley & Halligan, 2017). However, there are several theories about consciousness, which have influenced the field extensively, considering consciousness as to have an 'experience' nature. One of the first theories was proposed by Bernard Baars in 1989, as the Global Workspace Theory (GWT) model (Baars, 1988), in which consciousness is explained like a theater, where the conscious awareness is the light on the stage with characters move around and interact with each other, while the audience watching the play in the dark (i.e. unconsciousness), and the physiological process are behind the scenes as people like director, writer and anyone who shaped the actual scenes on the stage (a review is given by (Song & Tang, 2008)). Later on, the Global Neuronal Workspace (GNW) theory was proposed bringing the related neural activity of the brain to cognitive activities, into the picture (Dehaene, Kersberg, & Changeux, 1998). Another study drawing an understanding of consciousness, and more specifically the neural basis of consciousness, belongs to Francis Crick and Christof Koch, in which it is claimed that all conscious experiences (e.g. pain, visual awareness) have a basic mechanism in common, so understanding the mechanisms of one would lead to understanding them all (Crick & Koch, 1990). Giulio Tononi also proposed another theory on consciousness, which has widely been used by researchers recently, known as the Integrated Information Theory (IIT) (Tononi, 2004). According to IIT, having the capacity to integrate information, is the crucial property of a conscious system. The core belief of the theory is that consciousness exists intrinsically. Subsequently, IIT tries to build understanding framework that can, in principle, allow us to recognize systems that exist this way (that is, systems to be conscious), and also to find a way to measure consciousness (Tononi & Koch, 2015). There are several phenomenological features suggested for a conscious system in IIT, called axioms: Intrinsic existence, composition, information, integration and exclusion (Tononi, 2004). If one attempts to do research on consciousness, a definition needs to be clarified for the phenomenon. In this thesis, by inspiration from previous literatures (Tononi & Koch, 2015) having an 'experience' is defined as a conscious phenomenon.

A good model system to study consciousness needs to consist of variable states of consciousness, allowing to investigate its relation to brain activity, and consider the participants' will to confabulate if needed. The most accessible model for consciousness might be the state of wakefulness in humans, although for unconsciousness it is not that convenient. A possible candidate for an unconscious state would be, Unresponsive Wakefulness Syndrome (UWS), which is another name for vegetative state. UWS comprises of patients coming back from coma showing reflex movements while being unresponsive to external command (Laureys, et al., 2010). Since there are proofs of different levels of awareness for these patients, according to functional Magnetic Resonance Imaging (fMRI) studies (Cruse, et al., 2011), researchers avoid establishing the state of these patients as *vegetable-like*. Anesthesia, brain lesions and epilepsy are other potential conditions to be subjected for consciousness study. Another common and natural way to experience unconsciousness is to 'sleep'. The work presented in this thesis chose sleep to investigate conscious and unconscious periods among healthy subjects.

1.2 Sleep

Sleeping applies to one third of every human life-span, yet it is a whole un-known phenomenon. It is a naturally induced periods of unconsciousness (unresponsiveness) happening every once in every 24 hours of human life. As a biological function, sleep is not restricted to humans, and exists also in animals from Nematode worm to mammals (Keene & Duboue, 2018). It has been shown that sleep is related to the neural activities, and for years, scientists have attempted to find the most relevant brain regions responsible for sleep and arousal.

There are two important aspects of sleep known as, circadian sleep and homeostatic sleep. Circadian sleep regulates the sleep-wake pattern associated with day-night circulations, also known as circadian rhythm, every 24 hours. Homeostatic sleep, on the other hand, concerns mainly the biological need for sleep, which increases as a response to waking duration (Cirelli, 2009). There are some techniques, by which neural activity of the brain correlated with sleep can be measured; Electroencephalography (EEG) is one of the prominent ones.

1.3 EEG

EEG is a non-invasive neuroimaging technique, in which the neural electrical activity is recorded by means of electrodes placing on the scalp. On a cellular level, EEG recordings represent changes in calcium ion influx and hyperpolarization of neocortical (mostly pyramidal), and thalamic neurons which are synchronized enough as a neuronal population to be detected by EEG electrodes (Siegel, 2005). Figure 1.1 is an illustration of an aligned pyramidal population in the cortex, by which an electrical field is generated, captured by EEG electrode on the scalp, intensified by the amplifier, and result in the EEG signal. One of the possible disadvantages of EEG would be the requirement of high synchronicity; the smallest synchronous pyramidal cells' population needed to produce an EEG-measurable signal is estimated to ~100,000 cells (Cohen, 2017). This is why asynchronous neural activities and the ones in small-scale will either not be measured or hardly detected by EEG. Despite the disadvantages, EEG is one of the potential non-invasive techniques, which has been used to study healthy and diseased functions of the brain, since being presented by Hans Berger in 1924 (to check some of the first EEG recordings (Jung & Berger, 1979).

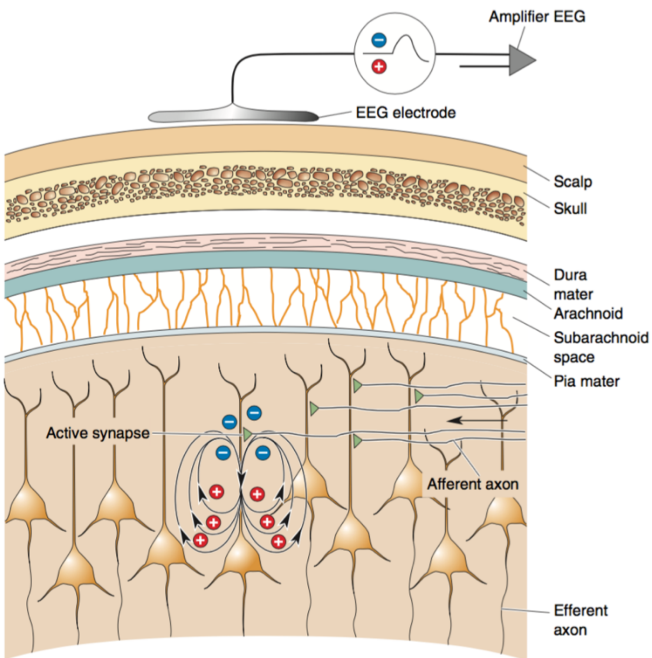

Figure 1.1. **The Origin of the EEG signal**: the electrical activity of the synchronous pyramidal cells in the cortex. Adapted from (Bear, Connors, & Paradiso, 2001).

There are other methods used to record brain activities, such as fMRI, Magneto-Encephalography (MEG), and Positron Emission Tomography (PET). fMRI seems to be a better methodology than PET, due to not requiring radioactive material injection to subjects, it has also a better spatial resolution compared to MEG. However, fMRI require a stable head position during recordings, and it produces a loud noise (up to 80 decibel) that would make it uncomfortable to sleep for the subjects (Erlacher & Schredl, 2008). EEG on the other hand, has a relatively weak spatial resolution, but higher temporal resolution than fMRI. Moreover, EEG is a cheap, portable and comfortable technique with a potential to do bedside detection of different diseases and consciousness measurements (Cruse, et al., 2011). EEG can efficiently capture the cognitive dynamic happening in a time domain varies from hundreds of milliseconds to seconds (Cohen, 2014). It also records directly the neuronal activity, which causes less signal bias by external noises (Cohen, 2014), while fMRI in principle measures the blood flow to brain regions. Hence, EEG as a direct measurement is more accurate than fMRI. One of the main phenomena, that has been characterized by EEG recordings is sleep and subsequently sleep stages.

1.4 Sleep stages

The normal sleep in humans comprises two main states: Rapid Eye Movement (REM) and Non-Rapid Eye Movement (NREM) sleep, that occur in a cycle across the sleep episode. REM sleep is known to happen late at night, with fast involuntary eye movements as its main characteristic. NREM sleep on the other hand, is involved in the beginning of nocturnal sleep, and subcategorized into four stages, based on Rechtschaffen & Kales (R&K) classification (Moser, et al., 2008). At birth, REM sleep takes 50% of total sleep and decreases over the first two years to 20-25% (Carskadon & Dement, 2011).

The differences of sleep stages have been studied with electrophysiological techniques like, EEG, EMG, Electro-Oculography (EOG) (Pace-Schott & Hobson, 2002). As shown in Figure 1.2 B NREM sleep is more frequent during the beginning of night, while, REM sleep increases in number and duration

at the end of the night. The EEG recordings during wakefulness presented in Figure 1.2 A, is low voltage and fast frequency dominant, within the rage of beta (>13 Hz) and alpha (8-13 Hz) frequencies. N1 is a transitioning state between sleep and wakefulness, where eye movements and muscle activities (visible with EMG) are still present, with theta waves (4-7 Hz) starting to appear. The next stage, N2, is mostly known for having K-complexes and sleep spindles, as oscillations in sigma band (12-16 Hz), and slow-oscillation spindles in 8-12 Hz. While N3 consists of 20-50% delta band (0.5-4 Hz) frequencies, more than half of the N4 stage is delta frequency dominant (Cirelli, 2009; Carlson, 2012).

It has been proposed that, many important physiological and cognitive activates are correlated with NREM sleep. For instance, it hast been shown that the process from short-term to long-term memory, also called memory consolidation, is related to brain activity during NREM sleep (Björn & Born, 2013).

Several prominent work around electrophysiological features of NREM sleep were influenced by Mircea Steriade from his research on cat brains, by means of ablation and intracellular recordings (Steriade M. , 2000). The main characteristics of NREM sleep, are the K-complexes, spindles, and slow frequencies as shown in Figure 1.2 C. According to Steriade's research, spindles are associated with cortical neurons' depolarization, resulting in long-term-potentiation (LTP) the process of strengthening the post-synaptic responsiveness by pre-synaptic high-frequency stimulations (Pace-Schott & Hobson, 2002) and finally taking part in learning and memory.

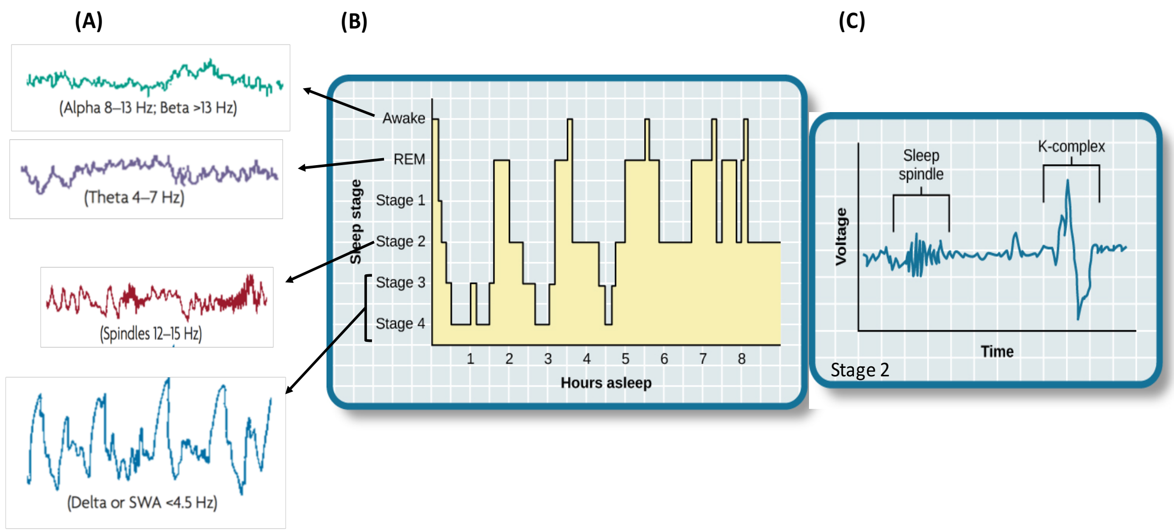

Figure 1.2. The EEG pattern associated with sleep stages A) The voltage fluctuations recorded by EEG for different stages of sleep. B) Distribution of different sleep stages during the night. C) Spindle and K-complex voltage pattern in NREM stage 2. (A) is adjusted from (Cirelli, 2009), (B&C) are retrieved from ("OpenStax College", n.d.).

Recalling dreams is known as a prominent and enigmatic feature of sleep. Since REM sleep has been traditionally considered as a sleep stage in which dreaming occurs the most (Pace-Schott & Hobson, 2002), it has been subjected in many studies (A review is given by (Hobson J. A., 2009)). However, it seems that REM sleep is not the only stage containing conscious experience. NREM sleep is also a compatible model for consciousness study, which has been considered more recently, due to containing both unconsciousness and conscious moments as dream episodes.

1.5 Dreaming

Dreaming is a mental experience, which 'usually' (excluding day dreaming) occurs during sleep. dreams are known to be one of the sleep's products, reported only among humans, due to his linguistic advancements (Bosinelli, 1995). This means that the only proof of dream's existence is the human's ability of 'recalling' it, rather than direct observation. However, one might not trust the dream-recall as a direct representation of a subjective experience during sleep, or even claims that dream reports are self-maid stories narrated right after awakening. While it is accepted as a challenging claim, studies have revealed that: I) the dreaming time reported by the subjects after awakening is correlated with the time spent in REM sleep (Stickgold, Malia, Fosse, Propper, & Hobson, 2001). II) dream reports from patients with REM sleep behavior disorder (e.g. disruption of muscle atonia), seem to match their movements in this stage (Leclair-Visonneau, Oudiette, Gaymard, Leu-Semenescu, & Arnulf, 2010), and III) the same claim applies to lucid dreamers, whose brain wave patterns in respect to their dream content, matches the brain patterns of the equal activities in real life (Erlacher & Schredl, 2008).

It is assumed that all kinds of consciousness such as, phenomenal consciousness, meta and self-consciousness are present, sometimes modified, during dreaming (Bosinelli, 1995). Thus dreaming is considered as a conscious experience or conscious mentation in this thesis. Mario Bosinelli suggested one of the first basic models for dream production in 1995 shown in Figure 1.3. Based on this model, the cassette-like memory elements (mnemonic materials) are activated while sleeping, and go from long-term memory storage to dream making system (bottom-up), then induce dreaming by interpretation, and elaborations (top-down), which again as a result of a circulation feedback activates or even inhibits other memory cassettes.

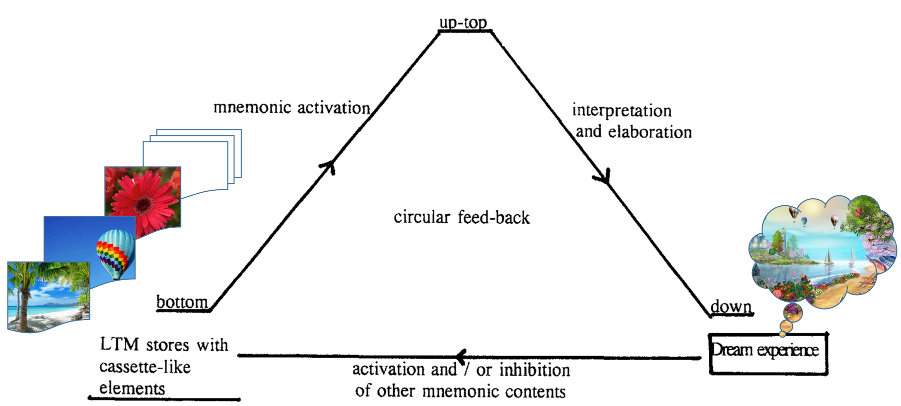

Figure 1.3. The Bosinelli's dreaming model. LTM: long-term memory. Adjusted from (Bosinelli, 1995).

Another model for the cognitive system of dreaming in REM sleep is shown in Figure 1.4, in which 3 states of wakefulness, NREM and REM sleep are shown respectively, based on their Activation, Input and Modulation system (AIM) in the brain. According to AIM, REM dreaming occurs when high internal neuronal activation is presented. Figure 1.4 illustrates the neurotransmitter regulations such as the level of acetylcholine, noradrenaline and serotonin, as external inputs to modulate vigilance in 3 presented states.

Later on, many studies have been done trying to figure out the relationship between conscious experiences during sleep and brain activity and the neural correlates of dreaming, by means of brain lesion studies, functional imaging and neurophysiology (Tononi & Nir, 2010). Among studies on sleep and consciousness, some have used awakening paradigms during sleep, and subsequent dream reports to provide empirical support to the theories for the conscious state.

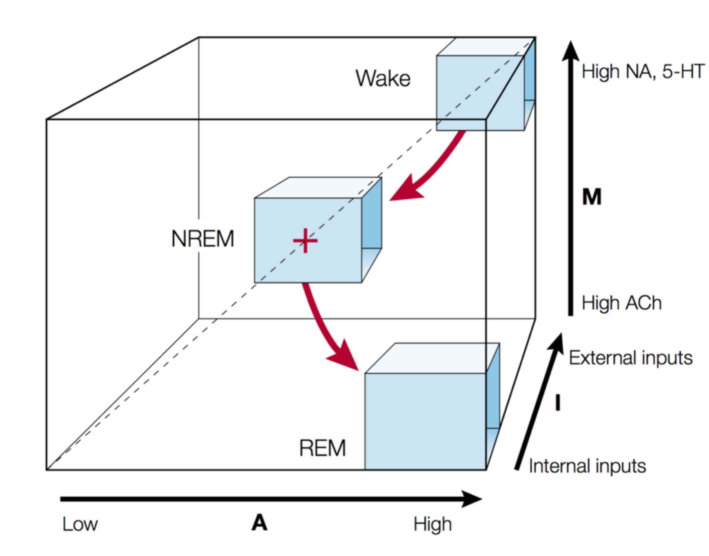

Figure 1.4. The AIM (activation, input, modulation) model of dreaming. The three-dimensional model of dreaming, shows the transitions from wakefulness to NREM and REM states, in respect to level of neural activation, internal/external inputs, and modulation with neurotransmitters. ACh: Acetylcholine, NA: Noradrenaline, 5-HT: 5-hydroxytriptamine (serotonin). Adapted from (Hobson & Pace-Schott, 2002).

1.6 Awakening paradigm

One of the main approaches to study consciousness during sleep is conducting direct reports from subjects. Sleep studies have the advantage of recording reports of conscious experience, by means of awakenings, which can easily be done in patients who experienced an epileptic seizure, or are in UWS. The sleep-awakening paradigm has been the methodology in many studies from the 90's until today.

There are studies using dream recalls in REM and NREM sleep, claiming that during NREM sleep, when delta waves and spindles are present, consciousness is suspended or maintains in a very low level (Dement & Kleitman, 1957). The idea that dream recalls have a REM-sleep origin was challenged by David Foulkes in 1962, who performed a questionnaire based on some protocols, in which subjects were asked, "what was going through your mind" instead of, whether or not the subject was "dreaming". He believed that, by this alteration, he would elicit dream-like materials which might have been missed before. Participants often demonstrate that they consider dream mostly as visual and bizarre phenomena. Since, NREM reports are mostly less visual and are in high correspondence with reality, not many would be collected if subjects assume "dream" is the only phenomenon the experimenter is looking for (Foulkes D. W., 1962). This type of questionnaire has also been used in recent studies (Siclari, LaRocque, Postle, & Tononi, 2013) (Siclari, et al., 2017; Siclari, Bernardi, Cataldi, & Tononi, 2018), as well as in this thesis (Table 1, methods). Moreover, the content of dream recalls has been investigated in several studies (Goodenough, Lewis, Shapiro, Jaret, & Sleser, 1965; Foulkes & Schmidt, 1983), claiming that NREM dream recalls are mostly thought-like than qualitative dream-like reports recruited from REM sleep. In order to study NREM sleep, the most prominent features of this stage must be clarified and investigated; slow oscillations are one crucial example.

1.7 Slow frequency activity

Since the terminology in EEG band, representing slow frequency activity of the brain is not consistent in the literatures, in this thesis the delta band frequency is related to 1 Hz (sometimes 0.5 Hz) to 4 Hz, where slow waves are present, which are linked to loss of consciousness (Siclari, et al., 2017). Moreover, the low-frequency activity is associated with frequencies lower than 1 Hz (0.25-1 Hz) (Lanquart, Nardone, Hubain, Loas, & Linkowski, 2017), and Slow Wave Activity (SWA) represents the power of delta frequency band which according to literature of reference is in delta range (Siclari, Bernardi, Cataldi, & Tononi, 2018). Slow oscillations between the depolarized up-state and hyperpolarized down-state in cortical neurons, cause slow wave oscillations of the brain during NREM sleep (Nir, et al., 2011). The origin of such activity is assumed to be thalami-cortical oscillations (Pace-Schott & Hobson, 2002). These oscillations are originated from a network within thalamus and cortex, which contains synchronously activating neurons (Jones, 2002). The neuro-modulatory activating inputs on this network such as, noradrenergic and serotonergic neurons has to diminish, so that the thalami-cortical oscillations can begin, and induce slow frequency activity of NREM sleep (Pace-Schott & Hobson, 2002). The circadian and homeostatic signals may be some of the factors to attenuate neuro-modulations (Saper, Chou, & Scammell, 2001). The low-frequency of the brain has first been shown with intracellular recordings in anesthetized cat (Steriade, Nunez, & Amzica, 1993), then in NREM sleep in human (Achermann & Borbély, 1997).

The slow wave sleep is known to be the stage of losing consciousness (Siclari, LaRocque, Postle, & Tononi, 2013). As mentioned earlier, the transition between neural up and down states cause a bi-stability by which the causal interactions among cortical brain areas are suppressed (Pigorini, et al., 2015), and an impairment in information integration occurs, so according to IIT, consciousness would be lost (Tononi, 2004). The loss of information integration in the brain is also the cause of unconsciousness during anesthesia, triggered by anesthetics (Alkire, Hudetz, & Tononi, 2008).

The delta frequency range has two possible sources of generation: I) inside the thalamus alone by intrinsic cellular membrane currents, II) in the cortex, while cortical neurons activate the thalamic interneurons, and result in thalami-cortical hyperpolarization, which generates slow waves by producing synchronous signals to the cortex (Pace-Schott & Hobson, 2002). There are studies that have investigated slow wave activity of the brain as a potential parameter to show differences between presence and absence of conscious experience during NREM sleep, and found a significant decrease in that parameter for dreaming consciousness (Williamson, Csima, Galin, & Mamelak, 1986; Esposito, Nielsen, & Paquette, 2004; Chellappa, Frey, Knoblauch, & Cajochen, 2011; Scarpelli, et al., 2017; Siclari, et al., 2017). Thus, the main focus of this thesis is on slow wave activity as the power of delta band (0.5-4 Hz), and linking it to the loss and gaining of consciousness.

1.8 Current study

During sleep, we are disconnected from the outside world, yet conscious in the brain to make pictures, characters, scenarios, and in some cases, vivid narrative stories with sensorimotor experiences, which are hard to believe to be hallucinatory after waking up. Although there is a pool of experimental data in sleep research, the relationship between subjective experiences during sleep and objective brain measures needs to be clarified. Using unconscious states like sleep accompanied by dreaming as a conscious event, has aided many studies including this thesis to find the markers of consciousness.

1.8.1 Aim and hypothesis

The main goal of this thesis is to bridge the gap between physical explanation of consciousness and subjective phenomenology of consciousness. NREM sleep is assumed to be a stage containing both conscious and unconscious moments, when regarding dream as a conscious experience. This thesis aimed to investigate potential EEG correlates of dreaming, by performing an awakening paradigm during NREM sleep stages in healthy subjects. Among different deep-sleep related parameters, the 'slow wave activity' was measured and compared between the two main states of having and not having a dream experience.

According to the growing literature in the field, we assumed that first and foremost, dreaming is a conscious behavior in which all types of awareness may be presented, with mild alterations relative to actual awareness. Based on the previous findings by Francesca Siclari et al. from 2013 to 2018, we hypothesized that:

1. There will be reports of both dream and non-dream experiences during NREM sleep.
2. There will be differences in brain wave patterns, when dreaming in NREM sleep compared to non-dreaming.
3. These differences will mainly consist of a decrease or increase in predominantly slow wave activity.

In sum, if the above hypotheses are supported, then we might conclude that low frequency power can be a potential marker for consciousness.

2 Methods

2.1 Participants

We recruited healthy volunteers (*n*=18, age: 18-35 yrs, 10 women) via posters on the local university campus and advertisement on social media. Participants were excluded from the study based on current neurological or sleep disorders, smoking, a non-dreamer, high coffee-consumption, or pregnant. Studies have shown that depression affects on sleep quality, latency, and reduces slow wave sleep (Borbely & Wirz-Justice, 1982). Furthermore, depression and anti-depressant medicines change sleep physiology by directly affecting the neurotransmitter systems. Selective serotonin reuptake inhibitors (SSRIs) for instance, prevent serotonin reuptake which would induce the feeling of joy and happiness (Argyropoulos & Wilson, 2005). By changing neuronal behavior, EEG pattern would change subsequently, thus subjects with the history of depression were also excluded. As a result, two subjects were excluded from the study due to medication and personal reasons. This led to a total of 16 participants (9 women) to go through recordings.

For the night prior to the experiment, participants were asked not to sleep for at least 20 hours prior to the time of the experiment, and special care was taken to inform them about the dream questionnaire, and possible risks of sleep deprivation. Moreover, it was inquired from them to rinse their hair with no conditioner before coming to the lab, and not to wear any kinds of facial cream, aiming to have better electrode conductance in following steps of the study. On the day of the experiment, all participants were informed about the experimental design, the process, and their right to withdraw from the test at any point during the experiment. Finally, their written informed consents were collected before the experiment was conducted. The study was approved by the Regional Committees for Medical and Health Research Ethics (REK) at the University of Oslo. Each participant received a 300 NOK gift card after the experiment.

2.2 Experimental design

The experimental procedural sequence, as depicted in Figure 2.1, started with a night prior to the main experiment where participants were asked to stay awake. On the day of the experiment, all participants were met at the hospital at 7:30 (± 10 minutes), in order to have a homogenous group in deprivation. Then participants were first asked to fill the sleep survey, while EEG electrodes were mounted and calibrated with a goal of impedance less than 5kΩ. The recordings started with eyes open and eyes closed resting spontaneous EEG (5 minutes each), followed by the sleep recordings with intermittent awakenings during NREM sleep stages 2-4 with dream questionnaires

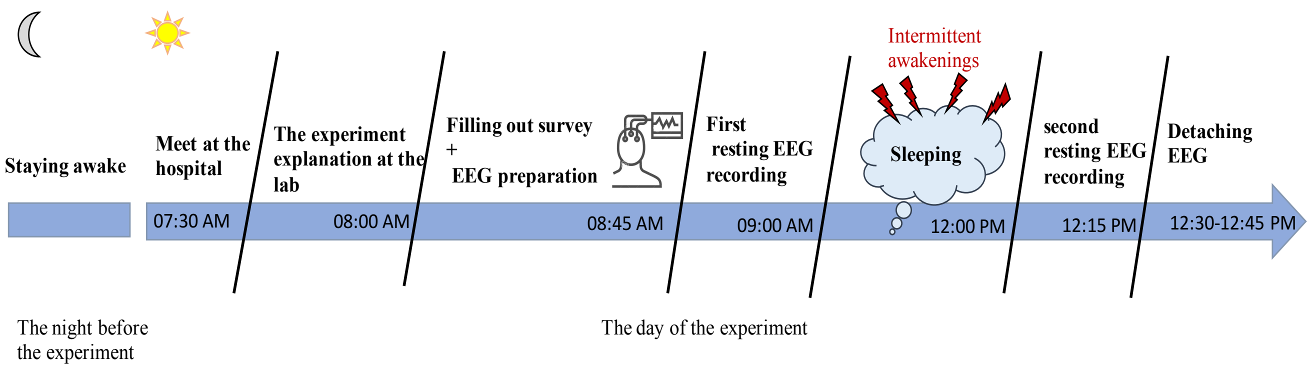

Figure 2.1. The experimental steps in time scale.

immediately following each awakening, M=6.06 times (±1.98) per subject. After sleep, another resting eyes open and closed EEG recordings was performed, and the test ended with detaching the EEG equipment.

2.3 Experimental setting

2.3.1 Sleep deprivation

While previous studies worked with sleep through the night in the lab (Siclari, et al., 2017; Siclari, Bernardi, Cataldi, & Tononi, 2018), in this study participants were instructed to stay awake for one night, without using caffeinated and alcoholic beverages. and come to the lab the following morning being sleep deprived. Sleep deprivation would affect the amount of time spent in different sleep stages, such as an increase of stage 4 sleep and enhanced slow wave sleep at the beginning of the sleep process (Borbély, Baumann, Brandeis, Strauch, & Lehmann, 1981). This would probably make sleep deprivation a suitable method for this study, which concentrates on deep sleep, however, it has been observed that sleep deprived subjects have an artifactual.

2.3.2 Sleep survey and dream questionnaire

The sleep survey was collected at the beginning of the experiment, which contained questions about the previous night activities, the sleep patterns and cycles during 3 weeks before the test, any medication use, and their current sleepiness right before starting the recording that registered by the Stanford Sleepiness Scale (SSS).

Table1 shows the dream report questionnaire asked immediately after each awakening. These questions were adapted from the previous studies on having subjective experiences during sleep (Siclari, et al., 2017; Siclari, Bernardi, Cataldi, & Tononi, 2018). The first question has been altered from "did you have a dream before the alarm clock?" to "what was the last thing going through your mind before the alarm sound" which has been argued to capture more dream-like experiences from participants (Stickgold, Malia, Fosse, Propper, & Hobson, 2001). The rest of the questionnaire (Table 1) was performed in the case of reporting a dream experience (DE) and stopped if no dream was experienced (NE). In case of having a dream experience without recalling the content (DEWR), follow up questions was asked to probe if he DEWR was a DE (Siclari, et al., 2017). For DEs, the subject ranked the experience from 1 to 5, as extremely thought-like to extremely perceptual. Questions followed with an estimation of dream duration, as well as reporting of sensory-related scenes such as, faces, movements, spatial setting and speech. The awakening process continued until the subject announced being well rested (i.e. unable to sleep), or the researcher claimed that it would be highly unlikely to have deeper stages of sleep following that time point.

Table 1. The dream report questionnaire.

<table>
<tr><td colspan="5">1. What was the last thing going through your mind before the alarm sound? (DE,DEWR,NE)</td></tr>
<tr><td colspan="5">Continue in case of having DE (and DEWR):</td></tr>
<tr><td colspan="5">2. Please rate your experience as:</td></tr>
<tr><td>1.Exclusively thought-like</td><td>2.Mostly thought-like</td><td>3.Equally perceptual and thought-like</td><td>4.Mostly perceptual</td><td>5.Exclusively perceptual</td></tr>
<tr><td colspan="5">3. Please estimate the duration of your last dream experience in minutes.</td></tr>
<tr><td colspan="5">4. Did your dream experience contain a face? (Yes/No)</td></tr>
<tr><td colspan="5">5. Did your dream experience contain spatial setting? (Yes/No)</td></tr>
<tr><td colspan="5">6. Did your dream experience contain movement (you or others moving)? (Yes/No)</td></tr>
<tr><td colspan="5">7. Did your dream experience contain speech? (Yes/No)</td></tr>
</table>

2.3.3 EEG

EEG is a neuroimaging technique, mostly used to measure electrical activity derived from neural firing in the brain. For this study, the EEG was recorded with two BrainAmp DC 32 channel amplifiers, and a 64 channel EEG cap (Brainproducts, 64Ch-EasyCap for BrainAmp with ECI electrode gel and NuPrep abrasive skin-prep gel) placed on the scalp, based on the international 10-10 system. The Brain Vision Recorder view software (version 1.4.3) was used for this measurement. Figure 2.2 B shows the places of the electrodes on the face and scalp. In order to record vertical and horizontal eye movements, two EOG electrodes were placed each one above the right and below the left eye. As shown in Figure 2.2 A, EMG electrodes were also attached on the mentalis muscle - the central pair of muscles of the lower lip located on the chin- while EMG reference was placed on the right side of the face above the buccinator muscle. EMG electrodes record the muscle activity during sleep, facilitating the the classification of sleep stages, as well as detecting artifacts. The EEG reference electrode was mounted on forehead, exactly above the nose midline, with Ground electrode next to it above the right eye (Figure 2.2 A).

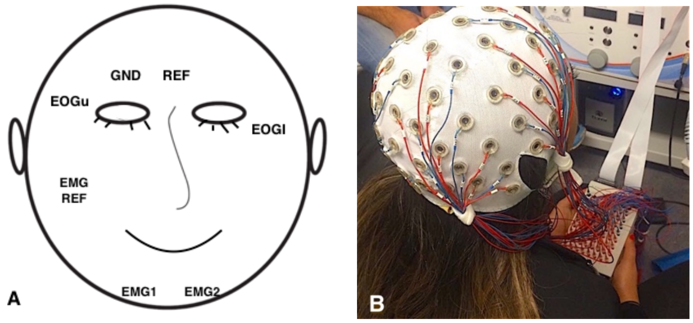

Figure 2.2. **Positions of the electrodes**. A: face-related positions, REF: Reference, GND: Ground. B: EEG cap mounted with 64 electrodes wired to the amplifier.

2.3.4 Acoustic

In order to facilitate sleep, as well as avoiding possible acoustic disturbances, a so called ‘brown noise’ (random walk noise) was played constantly through a headset with their preferred level of volume, through the whole experiment. Acoustic stimulations has been shown to be safe, enhance SWA during and following the period of stimulation, and increase slow waves and spindle coupling during sleep (Bellesi, Riendner, Garcia-Molina, Cirelli, & Tononi, 2014). In order to wake the subjects up an alarm sound was played through the headset for 2 seconds, when the researcher judged the subject to be in stage 2-4 sleep.

2.4 Experiment

2.4.1 Resting EEG recordings

Before the sleeping begins, two control measurements were performed. In the first control measurement, as presented in Figure 2.3, participants were asked to look at a fixation cross in front of them for five minutes, while sitting relaxed with minimum movements on a chair, with the brown noise playing on the background. Then another 5 minutes with close eyes were recorded. Although participants were demanded not to fall asleep during the control recordings, sleep-onset brain wave patterns were frequently observed as well as artifacts related to sleep deprivation.

After sleeping, another resting EEG was measured. Due to having bad impedances in some electrodes, they were adjusted with conductive gel if needed. This resting measurement was performed to investigate the effect of sleep deprivation on resting state EEG (not reported in this thesis). At the end of the procedure, EEG cap and related electrodes were removed.

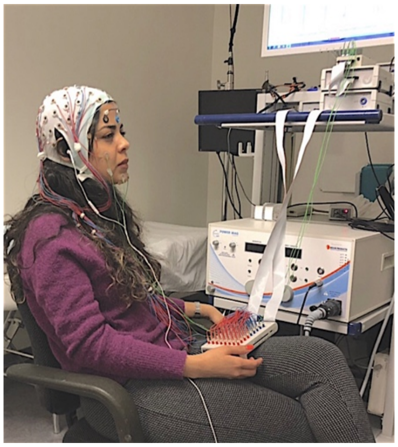

Figure 2.1. **Resting EEG**. First recording with eyes open and brown noise playing through the headset.

2.4.2 Sleeping

Subjects were welcomed to sleep on the lab bench with their preferable number of blanket layers as shown in Figure 2.4. After sleep procedure initiated, researcher(s) witnessed subject's transitioning from wakefulness to sleep and from sleep stage 1 to deeper stages, from their brain wave patterns on the screen. With at least 10 minutes sleeping in between, participants went through several awakenings, by means of an alarm clock played for 2 seconds. The researcher decided the time of awakenings, when the NREM sleep stages were visually identified. According to frequency oscillations, the muscle tone intensity and eye movements during sleep, researchers have been able to distinguish different stages of sleep and correlate them with collected dream reports (Aserinsky & Kleitman, 1953). In line with purpose of the study, subjects must be woken up in stages deeper than sleep stage 1, in order to have slow frequencies, which can be detected after observing k-complexes followed by spindles. Right after the alarm sound, the dream questionnaire was performed, while dream reports were being recorded (with prior confirmation) on a recording device.

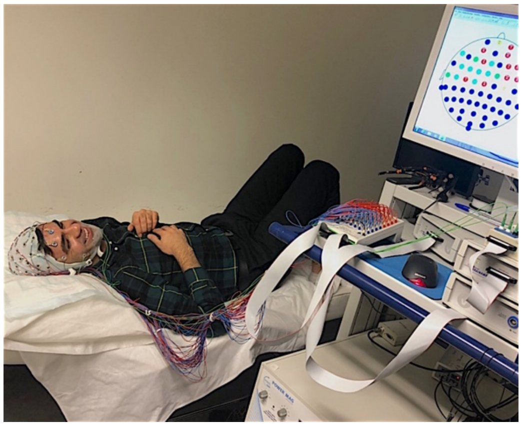

Figure 2.2. Sleeping Part of the experiment: showing the positions of amplifiers, computer monitor and sleeping bench.

2.5 Data Analysis

2.5.1 EEG analysis

EEG data in general contains signal and noise; the signal is the translated form of brain activity, while the noise is microvolt fluctuations coming from outside the brain. Despite of considering possible ways to make the lab situation as comfortable as possible, spontaneous EEG recording shows different kinds of artifacts, which mainly belong to physiological or non-physiological categories, resulting from electrical activity of the brain or the electrical devices in the environment of recording (Britton, et al., 2016). The known physiological artifacts like, eye movement, sweat, cardiac, pulse, muscle or general movements, are almost excluded from the data by EEG pre-processing. We employed an existing preprocessing pipeline ("Makoto's preprocessing pipeline", n.d.), using MATLAB (MathWorks, R2016b) and EEGLAB (version 14.1.1).

The pipeline goes through the following steps. EMG and EOG electrodes were remove from the data and were not considered in the pre-processing procedure. The high pass filter was chosen to be 0.5 Hz, while the low pass filter was at 40 Hz (cut-off frequency 0.25 and 80 Hz). The EEG data was down-sampled to 1000 Hz. Bad channels were rejected automatically with high precision by a clean-row data plug in. As EEG electrodes are not independent of each other (i.e. have some sources in common) bad channels were interpolated for, followed by an average referencing.

The final step of preprocessing was an independent component analysis (ICA). If consider the electrodes on the scalp each as a microphone, then each electrode records a sum of electrical activities coming from different parts of the brain with different intensities (in voltage) at a time point, like a microphone recording all the sounds made in an area at a time (Hyvärinen, 2013). The ICA's job is to help finding the original signals, which contain important information, though not easily recognized when looking at the observed signal (Hyvärinen, 2013). The data goes through ICA as a single matrix (channel voltage and time), and becomes a set of components with different ranks. Each component has pool of information, and ICA attempts to find the source signal behind the recorded signal. At the end of the preprocessing, bad ICA components get eliminated either manually or automatically. In this study they have been rejected automatically by ICLable. Figure 2.5 is illustrating how the bad components are selected.

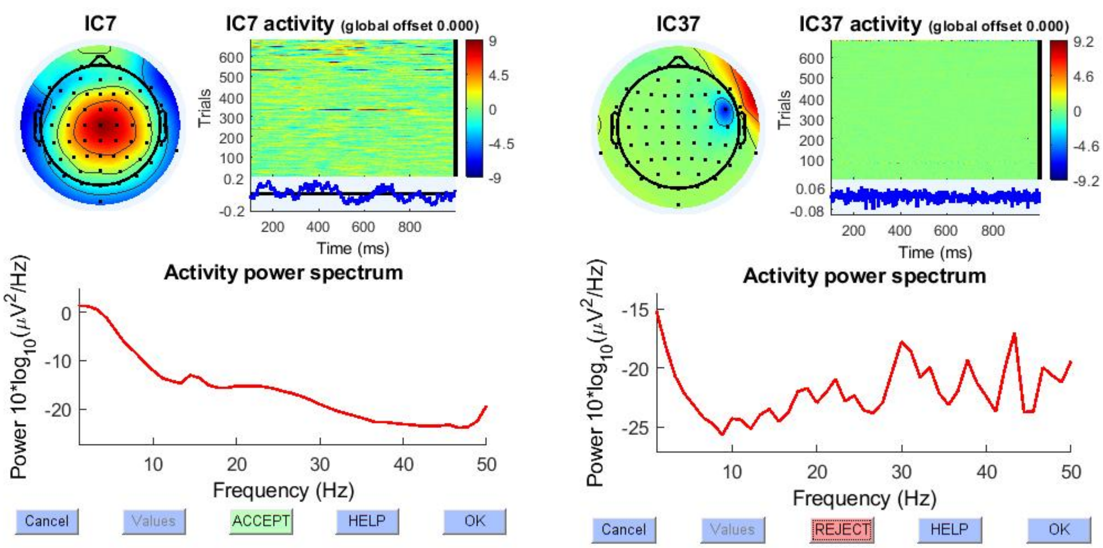

Figure 2.5. Two different ICA components: IC7 as a brain signal, and IC37 as a mucle artifact.

IC7 shows a component which assumed to be a brain signal, due to having a power increase around 10 Hz. On the other hand, IC37 shows a component which is highly possible to be a muscle activity. Bad components can be recognized not only based on the power-frequency plot, but also from the dipole created on the surface of the scalp, shown in the topography.

After the pre-processing was done, the data went through post-processing analysis, in which the delta frequency band was extracted in the range of 0.5-4 Hz. To achieve this purpose, the EEG data was referenced to the average of the two mastoid electrodes (Tp9 and Tp10), then the two mastoid electrodes were removed from the data, and the data down-sampled again to 128 Hz. Finally, the band-pass-filter (0.5-4 Hz with stop-band at 0.1and 10 Hz) were performed using a Chebyshev Type II filter (Matlab, The Math Works Inc, Natick, MA), based on previous studies

(Siclari, Bernardi, Cataldi, & Tononi, 2018). The SWA (power of delta band frequency 0.5-4 Hz), then was measured and normalized by 'decibel approach' around the baseline. The baseline was calculated over the whole trial (sleep/awakening test), independent of the trial type (DE/NE/DWER).

2.5.2 Dream analysis

For this study the first question in the dream questionnaire: "What was the last thing going through your mind before the alarm sound?", played the most important role in categorizing participant's reports into, DE, DEWR, and NE. The reports were associated with 20 seconds before the awakening. An illustration for a DE report was: "I was in a van, I was in the back seat and someone else was driving, but I don't know who and we didn't talk", while for NE, only the answer of "Nothing" to the first question (Table1) is considered relevant. Those reports are precisely distinguished from the dream-like reports without content such as, "I think I was somewhere, but I don't remember where" which is too vague to be a DE, so is considered separately (DEWR), however as noted, DEWRs were probed further to see if subjects could remember more. Due to limited scope of the current work, we focused only on the categorization of DEs, DEWRs, and NEs.

2.5.3 Statistical analysis

By measuring the SWA for each channel (60 channels in total: EOGs and mastoid electrodes are removed) for the two main groups (DE and NE), the comparability of the parameters was measured by permutation testing.

2.5.3.1 Permutation test

Permutation test is a hypothesis based test. It usually measures the effect of treatments on different experimental units, like measuring the efficacy of new drugs on cancer cells. It is also a non-parametric test, meaning that all the calculations are done without the assumption of having a normally distributed dataset. The test starts with having two groups with different conditions; DE and NE. The test follows with calculating the difference between the response values for each group members. For this study, we had the slow wave activity for each 60 channels in each awakening for each subject, as a result, 20 primary topographies for DE and 11 NE topographies became available. The average of powers for each channel among DE topographies and each channel among NE topographies were calculated, which resulted in having one topography for each state of DE and NE (as illustrated in Figure 3.2, results). Then, the mean-difference of each channel between DE and NE was measured, which gives us a topography of 60 channels, considered as the 'initial difference'. Then, assuming that null hypothesis is correct, with shuffling DE and NE primary topographies, the mean-difference was recalculated. By doing the shuffling for 10,000 times, a statistical distribution of mean-differences, which is a normal distribution, will be given. Figure 2.6 shows an illustration of mean-difference distribution that can be obtained under the null hypothesis (for each channel) after permutation test. The position of the 'initial difference' can now be observed within the distribution. The next step is to calculate the *p*-value, which is the probability of getting the observed value (initial difference), assuming the null hypothesis is correct. Based on the initial-difference's position in the distribution *p*-value is measured. According to "significant value", which was decided to be 5% (Figure 2.6 is showing the higher end of 2.5% in red circles), and position of *p*-value accordingly, the difference between two groups is either significant or insignificant. Thus, if *p*-value is in the 2.5% of higher or lower end of the distribution, it would mean that it is unlikely to be coincidental. If so, the null hypothesis would be rejected, and there would be a significant difference between the two groups of data.

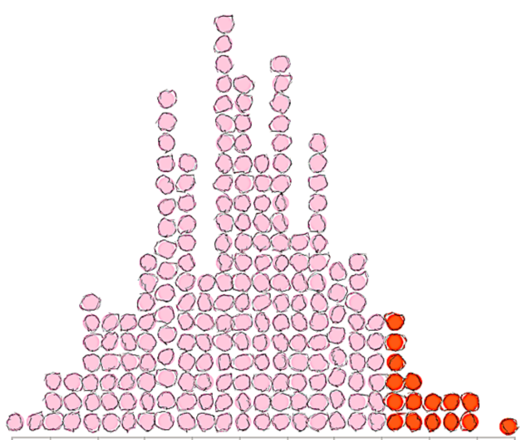

Figure 2.6. A schematic view of distribution of the mean differences, calculated by permutation test. The X-axis is the amount of the mean difference and the Y-axis is the quantity of each value. The red area contains values with less than 2.5% probability. Adapted from (Wilber, 2019)

3 Results

3.1 Dream reports

From 16 subjects who went through recordings, one was excluded before the analysis, due to not transitioning to sleep stages during the experiment. The 15 final number of subjects went through 90 awakenings (M=6.5 ± 2.22 SD per subject) during NREM sleep stages, with 60 awakenings with dream experience (Total (t) dream experience: $DE_{(t)}$ = 66.66%), 11 with non-dream experience ($NE_{(t)}$ = 12.22%), and 19 awakenings containing dream experience without recalling the content ($DEWR_{(t)}$ = 21.11%). Based on the purpose of our study, to compare two main states of having and not having subjective experiences within subjects, only participants with combination of DE and NE were extracted for delta frequency band. Figure 3.1 shows a distribution of three types of phenomenological experiences for 40 awakenings in those 6 subjects, with 20 awakenings associated with DE (50%), 11 with NE (27.5%), and 9 with DWER (22.5%). The DEWR reports are not analyzed as they are outside the scope of this thesis, but might be analyzed in the future.

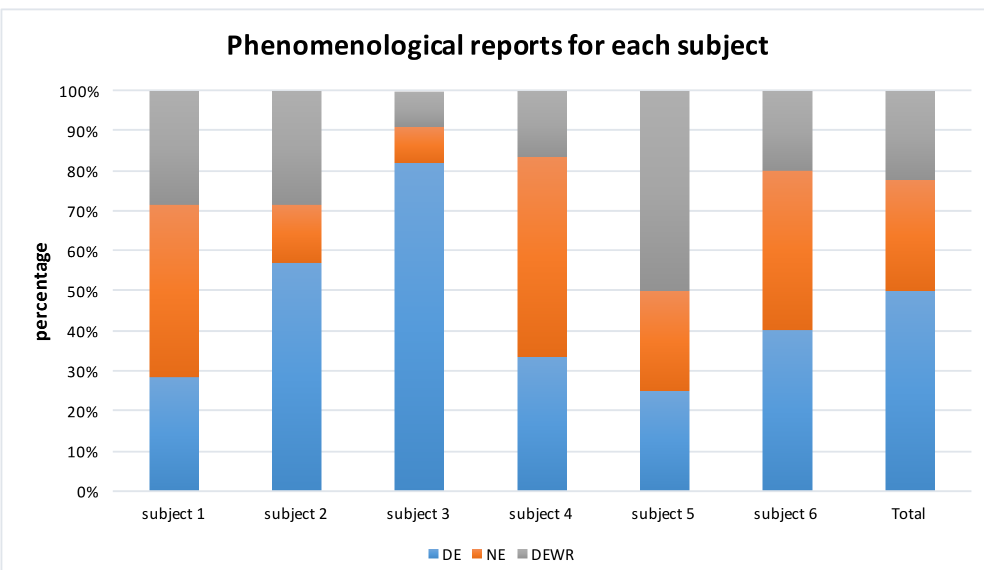

Figure 3.3. The proportion of each phenomenological experience for the final 6 subjects. DE in blue, shows the dream experience. NE in orange shows the non-dream experience and DEWR in gray represents the dream reports without content.

3.1.1 Slow wave activity

The slow wave activity (SWA) for 60 channels, with 31 awakenings (DE & NE) among total number of 6 subjects, was calculated as power of the delta frequency range 0.5-4 Hz. Figure 3.2 shows the topographical mean power of 60 channels, in two conditions (DE and NE). As it is illustrated in Figure 3.2 DE is showing the mean power from 20 awakenings with dream recall, and Fig.3 NE shows the mean power resulted from 11 awakenings containing no experience. Lower SWA (marked in blue) was observed in mostly the fronto-central and fronto-parietal regions, relative to the frontal and parietal areas (marked in red).

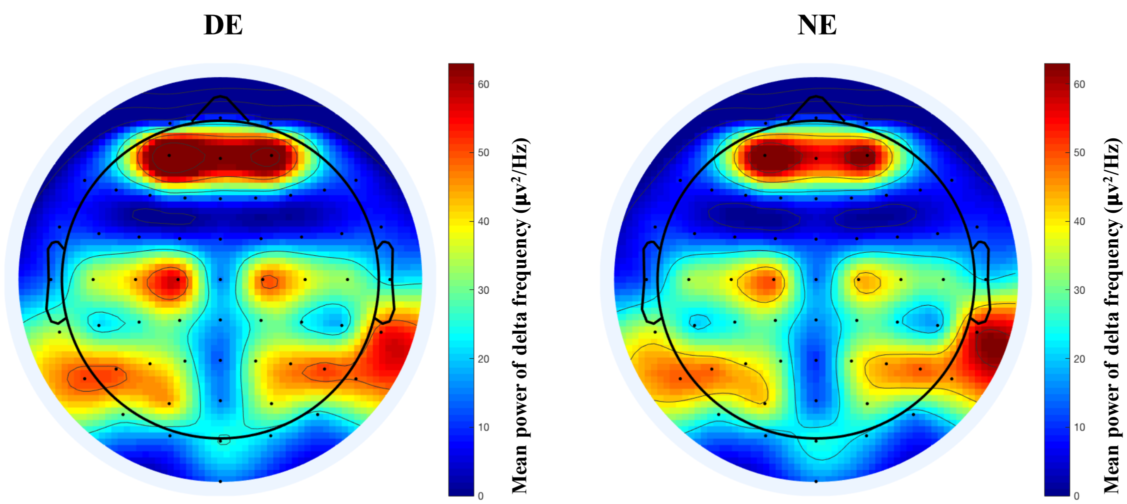

Figure 3.2. The topographies representing the SWA for 60 channels. showing the mean of slow wave activities for each channel in dream experience (DE), and none-dream experience (NE).

In order to have a closer look at the differences in SWA between channels, 4 channels were chosen arbitrarily, as shown by channel locations in Figure 3.3 A, from frontal, occipital and parietal regions, and the mean of SWA for DE and NE, was calculated for each channel. Furthermore, the mean across those 4 channels was also computed, as shown in Figure 3.3 B respectively. As it is presented in Figure 3.3 B, while the mean of SWA for NE (yellow bar) is lower than DE (blue bar), the difference is non-significant.

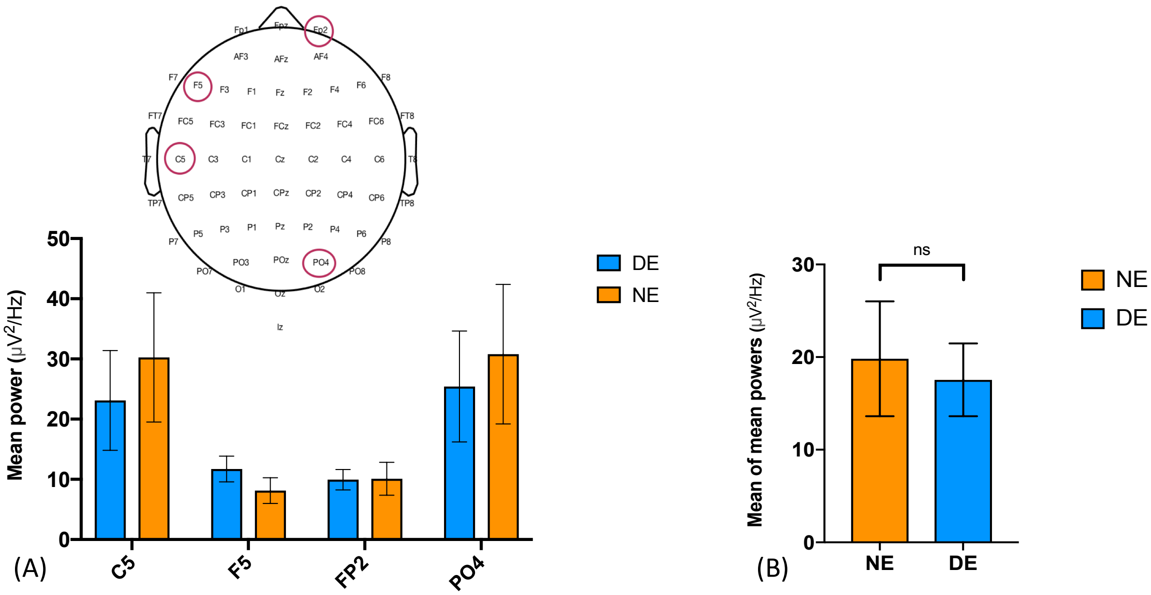

Figure 3.3. The SWA in 4 arbitrary chosen channels: A) the SWA for each of the 4 channels in two states of DE and NE, B) The mean SWAs in DE and NE. The error bars: Standard Error (SE). ns: non-significant.

3.1.2 *p*-values

Following the permutation test for each channel, between the two types of phenomenological experiences (DE and NE), we observed no significant difference in SWA, for any of the channels ($p>0.15$ for all channels). Values for each channel are presented in Table 2, accompanied by channel labels.

An illustration for the *p*-values associated with each channel is illustrated in Figure 3.4, in addition to channel locations on the scalp. According to Figure 3.4, the lowest *p*-values belong to the frontal and temporal channels, while the highest *p*-values are observed from parieto-frontal to parieto-occipital areas. The *p*-values are not corrected for the multiple comparisons problem, since there was no significant difference observed.

Table 2. *P*-values associated with each channel

Channel number	AF3	AF4	AFz	C1	C2	C3	C4	C5	C6	CP1
P-value	0.19	0.21	0.28	0.48	0.51	0.93	0.66	0.28	0.28	0.65
Channel number	CP2	CP3	CP4	CP5	CP6	CPz	Cz	F1	F2	F3
P-value	0.92	0.85	0.68	0.62	0.61	0.51	0.48	0.41	0.54	0.95
Channel number	F4	F5	F6	F7	F8	FC1	FC2	FC3	FC4	FC5
P-value	0.85	0.73	0.67	0.53	0.44	0.39	0.46	0.67	0.78	0.93
Channel number	FC6	FCz	FT7	FT8	FP1	FP2	FPz	Fz	Iz	O1
P-value	0.87	0.69	0.55	0.54	0.56	0.53	0.48	0.46	0.53	0.59
Channel number	O2	Oz	P1	P2	P3	P4	P5	P6	P7	P8
P-value	0.65	0.74	0.93	0.85	0.50	0.38	0.46	0.51	0.70	0.85
Channel number	PO3	PO4	PO7	PO8	POZ	Pz	T7	T8	TP7	TP8
P-value	0.95	0.82	0.71	0.76	0.31	0.42	0.61	0.43	0.15	0.17

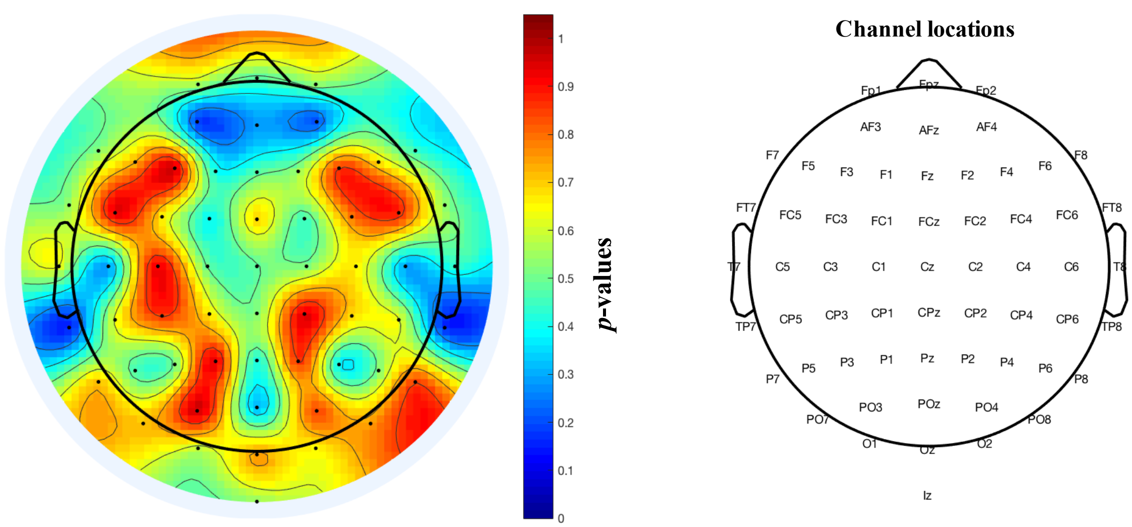

Figure 3.4. The *p*-values. Left: the topography of *p*-values associated with each channel. On the right: channel locations for 60 post processed channels.

4 Discussion

Since consciousness is a subjective phenomenon, it is accessible only from the first person (Overgaard, 2017). Thus, collecting reports after specific conscious/unconscious experiences is currently perhaps the only way to infer if a subject was conscious/unconscious prior to the report. As we assume that consciousness is in fact not only present in ‘every-day’, but also in ‘every-night’ life, dreaming during sleep is a valuable model when studying consciousness (Tononi & Nir, 2010). We aimed to investigate whether there is any difference between slow wave activity (SWA) in human NREM sleep electroencephalogram (EEG) in respect to having or not having a dream experience. We observed no significant differences between dream experience (DE) from none-dream experience (NE) and that with respect to SWA, contrary to what has been previously reported (Siclari, et al., 2017; Scarpelli, et al., 2017; Chellappa, Frey, Knoblauch, & Cajochen, 2011; Esposito, Nielsen, & Paquette, 2004), but in line with the most recent study (Wong, et al., 2019). As such, this might indicate that either the level of SWA in EEG during NREM sleep is not sufficient as base to distinguish DE and NE, or that we failed to capture any such difference due to methodological issues or failed understanding of when and how dreams occurs. Another possibility is that SWA alteration, as decreasing in delta frequency power, is not a genuine marker for dreaming consciousness, despite what most of the previous studies have inferred.

4.1 Dream reports

Regarding our first hypothesis, we did find both dream and non-dream experiences during NREM sleep, though not in all participants. 9 subjects out of 15, failed to give both two main types of conscious/unconscious experiences, and surprisingly, all 15 subjects did report dream experience at least once during the experiment. This lack of reporting non-dream during NREM, a stage that has been known to be dominated by slow waves and unconscious moments, was fairly unexpected, and raised several questions; it can be due to methodological flaws such as lab situation, sleep deprivation or the awakening process.

While early studies on dream recalls only concentrated on REM sleep, and assumed NREM dreaming to be a delayed report of REM-originated dreams (Dement & Kleitman, 1957), or an awakening artifact (Foulkes D. W., 1962), other studies provided evidence showing that dreams

occur frequently on stages 2 and 3 (Goodenough, Lewis, Shapiro, Jaret, & Sleser, 1965; Foulkes & Schmidt, 1983; Antrobus, Kondo, Reinsel, & Fein, 1995). Even after NREM dreaming entered the experimental research, the contents of the dreams were mostly considered as thought-like (Foulkes D. W., 1962; Don65; Foulkes & Schmidt, 1983), and to be different from REM dreams which is more perceptual and scenario-based. Despite of differences across REM/NREM dreaming characteristics, there are still isomorphism between the two states among phenomenology and physiology of dreams (Hobson, Pace-Schott, & Stickgold, 2000). We also have observed in this study that NREM dream reports varied from extremely though-like to extremely perceptual among subjects, however the content of DEs are going to be analyzed profoundly in future analysis.
There has been dream recall with a rate of 50% reported for awakenings during NREM sleep, especially in stage 2, by Foulkes on 1962. Moreover, changing the first question from "Tell me whether you had a dream?" to "What was the last thing going through your mind?" resulted having up to 70% conscious experiences during NREM stages, in previous researches (Stickgold, Malia, Fosse, Propper, & Hobson, 2001). Our results show a high number of DEs in total of 66% and 12% of NEs among all 15 subjects. Although this might be in line with few findings in dream recalls, it disputes several other studies, such as Francesca Siclari's, where only 34% (Siclari, LaRocque, Postle, & Tononi, 2013), and 31% (Siclari, Bernardi, Cataldi, & Tononi, 2018) of the NREM awakenings involved dreaming.

Since dream reports were collected from sleep deprived subjects, it could be compared to studies in which sleep deprivation or sleep restrictions has affected the rate of dream recall. Luigi De Gennaro and colleagues published their findings in 2010 on the affect of sleep deprivation on dream recall, and reported a significant decrease in dream recall for the recovery sleep after 40 hours of sleep deprivation, in respect to adaptation and base-line nights with normal sleep. This was observed, while the number of dream recalls did not change significantly, but the number of subjects who could actually recall a dream diminished, after morning awakenings (De Gennaro, Marzano, Moroni, Curcio, Ferrara, & Cipolli, 2010). Thus, our results disputed their conclusion, by which they stated that dream recalls are impaired during the recovery night after sleep deprivation. Siclari (2014) on the other hand, has shown an increase in the number of DEs for 4 subjects out of 7 in case of higher sleep restrictions, but since they recruited reports during the night and our reports are from morning awakenings, we cannot do an optimum comparison.

In addition to the numerous dream reports resulted in this thesis, the proportion of DE vs. NE according to our result, is higher than Siclari's results on 2018, in which DE involved in 31% of the reports, and NE in 30%. Also the 41.46%, proportion of DE and 53.68 % for NE was reported by Scarpelli and colleagues on 2017. Based on our results, the number of NEs are fewer than DEs (11 to 20), in addition to having only 6 subjects for the analysis. This means that the mean powers calculated for NE (illustrated in Figure 3.2 as a topography) is from fewer data than DE, and it would result in a poor statistical analysis.

Having numerous conscious experiences from subjects in our results might have several reasons. The 'learning effect' is one of them, according to which, participants report in favor of the purpose they might have interpreted from the study: to have at least some conscious experiences. However, all subjects were informed that all 3 types of reports (DE, NE and DEWR) are valuable for the study, they claimed to worry about not having a dream in the lab. Therefore, it might be inferred that some dreams might be self-driven. Sleep deprivation is another possible influential factor on dream rate, in which, homeostatic sleep needs to win over circadian sleep, when sleeping is allowed in the morning. This is worth investigating since, according to recent findings the two types of sleep regulations seem to be interconnected (Cirelli, 2009). This seems to be a noticeable factor, as none of the mentioned literatures on SWA has done the morning awakenings with no prior adaptation session, and with whole night sleep deprivation. The effect of recovery sleep condition on awakening in the morning can potentially be subjected for more research.

Another challenging point is that how much dream recalls can be trusted? It can be speculated that the scenarios reported by subjects are made during the wake up moment, which is too noisy to be considered in the data analysis, or confabulated by their minds after being questioned about it. In general, dream is known to happen in sleep, with the proof from some studies like, REM sleep disorder (section 1.5 introduction) or lucid dreaming studies (Erlacher & Schredl, 2008). Nevertheless, it is arguable that not all conscious experiences reported after awakening would have occurred during sleep, also there is no unequivocal empirical evidence on EEG correlates of dream recall (Scarpelli, et al., 2017). Hence, the idea that dreams can be triggered by the awakening process is a suggestion, which needs more investigation to be able to explain the existing reports of our study.

Generally, it seems that sleep might not be a pool of unconsciousness with brief conscious moments happening inside; it might be the opposite. “we greatly underestimate how often and how much we are conscious during sleep” (Tononi & Nir, 2010). Further investigations with larger group of data needs to be done to support such claim that consciousness dominates not only the REM sleep, but also NREM sleep.

4.2 Slow wave activity

The third hypothesis of our study regarding tracing the differences between DE and NE back to SWA, was not supported by the results, in which no significant difference between the two states was measured. Subsequently, the second claim of this thesis, which regards to the differences between DE and NE’s EEG patterns, cannot either be validated by our results. Despite the support of previous studies on the decrease of delta frequency power in presence of a dream recall (i.e. consciousness, mentation), the idea that delta power does not necessarily be a hallmark of consciousness can be debated, which would discuss our last hypothesis.

The EEG correlation of dreaming, specifically during NREM stages, have gone through investigations by several studies (Williamson, Csima, Galin, & Mamelak, 1986; Esposito, Nielsen, & Paquette, 2004; Chellappa, Frey, Knoblauch, & Cajochen, 2011; Siclari, LaRocque, Postle, & Tononi, 2013; Siclari, et al., 2017; Scarpelli, et al., 2017; Siclari, Bernardi, Cataldi, & Tononi, 2018; Wong, et al., 2019). Based on previous findings a significant decrease in delta power was consistently shown by Siclari (2017) in range of 1-4 Hz frequency, Scarpelli (2017) in 0.5-4.75 Hz, Chellappa (2011) in 1-3 Hz, and Esposito (2004) in 0.5-4 Hz, as to be a hallmark of consciousness during NREM sleep. The same decrease has also been reported by Williamson et al., (1986) in the delta-theta frequency range of 0.5-7.5 Hz. On the contrary, William Wong and colleagues have released their findings very recently (May2019), in which they reported their failure to replicate Siclari’s results in respect to SWA, hence they challenged the delta power to be a marker of dreaming consciousness.

It has been claimed that the high SWA is mostly associated with dreamless sleep, while having conscious experience have shown to decrease the SWA (Siclari, et al., 2017). Based on this thesis, although there has been a difference in SWA among channels (Figure 3.2), SWA shows no significant difference between two main states of DE and NE. This is shown in Table1, where no *p*-values reached the significant threshold (<0.05), and Figure 3.4, in which a non-significant difference can be observed between states. Although, no source reconstruction was done in our analysis, Figure 3.2 shows a higher SWA in the frontal channels in both states. There is a non-significant decrease in power of DE for the 4 arbitrary chosen channels (Figure 3.3 B), however the difference is not statistically significant.

The SWA changes were reported not to be global; on their study on 2017, Siclari and colleagues have performed sleep/awakening paradigm during the night for healthy subjects in two groups of trained (to have a higher number of awakenings) and untrained subjects, and collected reports in both REM and NREM sleep. The authors found a decrease in delta frequency power (range of 1-4 Hz) in NREM sleep stages, restricted to the posterior region (hot zone), when subjects had a dream experience. The same result was obtained for REM sleep. Additionally, an increase in the delta power has been shown in hot zone when no dream experiences were reported. The SWA results in accompanied with high-frequency (Gamma band 20-50 Hz) power, were promising enough to provide predictions of presence or absence of a conscious experience in NREM sleep in real time, with a high accuracy of 91.6% for DE and 80.7% for NE (Siclari, et al., 2017). They later expanded their findings by investigating the relationship between features of slow wave and spindles, as hallmarks of NREM stage, and dream experience (Siclari, Bernardi, Cataldi, & Tononi, 2018). Accordingly, they reported a decrease in frequency and amplitude of slow waves (0.25-1 Hz) in the whole brain for dreaming experience compared to non-dream experience.

Another relevant study discussing how synchronized EEG activity would prevent the retrieval of dream contents, belongs to Serena Scarpelli and colleagues on 2017. They have performed an awakening paradigm during evening nap (2 p.m.), and collected information regarding number and characteristics of dreaming form the diary written by the subject after the awakening. While mentioning that sleep cycle has no effect on dream recall, the authors claimed that dream experience is predicted by a lower delta activity compared to no dreaming, in the left hemisphere (Scarpelli, et al., 2017). The same conclusion has been made by Cellappa and colleagues on 2011, who recorded EEG during both REM and NREM sleep with a nap protocol awakening, and found a lower delta power, mostly in frontal areas of the brain, in respect to having dreams during NREM sleep. They also assessed spindle activity, as well as alpha and beta frequency power comparing dreaming consciousness and non-dreaming.

Although, our results disputed most of the previous findings, they are supported by the latest study in the field. William Wong and colleagues have recently performed a ‘dream catcher’ method to collect dream reports during NREM sleep, aiming to find the same results as Siclari’s group and several others’ in respect to SWA (Esposito, Nielsen, & Paquette, 2004; Chellappa, Frey, Knoblauch, & Cajochen, 2011; Scarpelli, et al., 2017). Having two groups of experimenters, data team and blinded analysis, Wong’s group attempted to assess both EEG pattern of NREM sleep associated with DE and NE, aiming to find a decrease in delta band power, and doing predictions based on Siclari’s findings. They have shown that neither of the purposes could be achieved, and claimed that what was measured as delta-power change during dreaming is in fact an indicator of sleep depth and not dreaming consciousness. Although more investigations are needed to explain such contradiction, Wong’s conclusion, in which there is no signature of phenomenal consciousness carried by EEG spectral power, is in line with our results.

Generally, a more profound understanding of consciousness is required both for theoretical studies and clinical applications. Despite of possible methodological errors, that would cause our results to be false negative, our findings indicated that SWA may not solely be a good marker for consciousness. We believe that our findings would aid future research to validate existing data in the field. The EEG-based data analysis demonstrating presence of conscious experiences would be beneficial in many ways. At some point it could become a bedside detection technique to provide vital information about the presence or absence of conscious experience in patients, in critical conditions like UWS (Cruse, et al., 2011).

4.3 Limitations

There are some limitations regarding the methodological and analytical part of our study. First, too NEs. This is mainly an issue of statistical power. To improve power we could be covered with higher number of subjects and/or awakenings. Siclari and colleagues (2017) used 10 awakenings per untrained subject and 113 per trained subject, while in our experiment the number of awakenings were nn average, 6.5 (±2.22 SD) per subject (for final 6 subjects). One possible reason for this could be reduced sleep quality in the lab.

The factors influencing sleep quality in the lab can be lab situation and circadian rhythm dominance. Since participants were not adapted to the lab situation, they might have experienced a lack of sleep depth, which could be due to a noisy and novel environment, uncomfortable sleeping position (EEG cap, equipment, etc.), and time of day. Specifically, Tamaki and colleagues (2016) studied sleeping in novel environments and observed that, when sleeping in a novel place, a default-mode network associated with mind-wandering avoids one of the hemispheres. Their interpretation is that one hemisphere is inhibited from going to sleep and in effect thus keeps vigilance to outside stimuli, termed a “night wath” (Tamaki, Bang, Watanabe, & Sasaki, 2016). Since there was no adaptation session prepared prior to the test day, participants might have experienced fewer, shorter, and lighter sleep episodes in the lab. This is in line with the ‘first night effect’, proposed by Agnew Jr. and colleagues (1966), according to which, participants would experience less REM sleep and a delayed transition to NREM sleep stage 4, during the first night sleeping in the lab compared to the second. Moreover, as the computers and EEG equipment was placed in the same room as the participants and thus presence of researcher(s) was required, participants might also be unaccustomed to sleeping with other persons present.

Another limitation is using recovery sleep in the morning (after sleep deprivation) instead of during the night which participants might be more accustomed to, which might be a limitation if its causality to dream recall changes is reported. Prior studies have recorded EEG during the night (Williamson, Csima, Galin, & Mamelak, 1986; Esposito, Nielsen, & Paquette, 2004; Siclari, LaRocque, Postle, & Tononi, 2013; Siclari, et al., 2017; Siclari, Bernardi, Cataldi, & Tononi, 2018) or nap time in the evening (Scarpelli, et al., 2017; Chellappa, Frey, Knoblauch, & Cajochen, 2011), whereas our recordings were done during the morning with sleep deprived participants. It has been demonstrated that sleep deprivation does not disturb NREM sleep, and enhances SWA during it (Borbély, Baumann, Brandeis, Strauch, & Lehmann, 1981), however, one can speculate that it might induce dreaming, especially during morning sleep. Sleeping in the morning period has been reported to be different from nocturnal sleep, in having a battle between circadian sleep and homeostatic sleep. According to previous findings, even minutes of blue light (morning light) exposure can be influential on brain function, especially when accompanied by homeostatic sleep pressure (Vandewalle, et al., 2011).

A methodological difference in our experiment is we employed 64 channel EEG instead of high-density 256 channel EEG to record brain wave patterns as was the norm in previous studies

(Siclari, et al., 2017; Siclari, Bernardi, Cataldi, & Tononi, 2018). Although we believe this would not make a big difference in the overall results, it can be influential when taking all limitations into account.

Finally, the awakening paradigm was performed by visually inspecting sleep stages in this thesis, while other studies used sleep scoring (see for example Rechtschaffen & Kales 1986) methods to be sure participants were in the intended sleep stages prior to awakenings. Since, it is assumed that the rate of dreaming is high in sleep onset and stage 1 and gradually diminishes when entering sleep stage 2, 3 and 4 (Siclari, LaRocque, Postle, & Tononi, 2013), the absence of sleep scoring in our data proposes the idea that we might have had several awakenings during sleep stage 1.

4.4 Future studies

Although the SWA difference in this study did not reach significance, our results have the capacity to be investigated more thoroughly. Post hoc analyses need to be carried out to identify the source of the results' inability to replicate previous findings. Future work should focus on, among other; having a larger group of participants, having a higher number of awakenings, vary the time of day for sleep to account for circadian rhythms, and include adaptation session(s) prior to the test day. Analytically, data source reconstruction is needed to compare different brain areas, which requires Magnetic Resonance Imaging (MRI) of the subjects' brain. Furthermore, multivariate analyses can be applied to future works, as William Wong suggested; the correlates of dreaming consciousness during NREM sleep might be found by multivariate analysis rather than univariate analysis (Wong, et al., 2019).

5 Conclusion

This thesis aimed at investigating if there are detectable signatures in the EEG signals during dreaming. We measured SWA in EEG during NREM sleep for periods of subjectively reported dream experience and non-dream experience. Based on the results, periods of NREM sleep with dreams did not show a decrease in SWA and neuronal synchronicity, contrary to predictions. Our results are similar to a recent comprehensive investigation into dreaming and non-dreaming sleep which also showed an inability to separate the two states (Wong, et al., 2019). In sum, we conclude that SWA is insufficient alone as neurological marker of conscious experience during NREM sleep.

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