COMMUNICATION WITH A SLEEPING PERSON

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ABSTRACT

Communication with a Sleeping Person

The aim of this study is to develop a method with which it is possible to exchange arbitrary messages with a sleeping person.

For this purpose, first, the theoretical basics of sleep and dreaming are summarized, giving an overview of previous works in this field. Second, the Theory of Sleep Communication is developed, which describes the method and its requirements by which it is possible to send messages with arbitrary content from the wake world to the sleep world and vice versa from the sleep world to the wake world, using dream incorporations, lucid dreaming, body signaling and a message coding scheme. Next, the Sleep Communication Framework is outlined, which defines the technical requirements for a completely automated sleep communication: the hardware, the software and the interfaces by which these parts are connected. Furthermore, a sample real-world implementation is presented. The theory, the framework and its sample implementation are finally tested in a pilot study, which demonstrates that sleep communication is indeed possible using the procedure developed in this thesis. After summarizing and critically discussing the results of this thesis, future prospects of sleep communication are briefly outlined.

Key words: sleep communication, theory, framework, implementation, lucid dreaming, arbitrary messages, two-way

DECLARATION OF AUTHORSHIP

I hereby certify that the work presented here is, to the best of my knowledge and belief, original and the result of my own investigations, except as acknowledged, and has not been submitted, either in part or whole, for a degree at this or any other university.

signature

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LIST OF ABBREVIATIONS

ANN: Artificial Neural Network

EEG: Electroencephalography

EOG: Electrooculography

EMG: Electromyography

kNN: k-Nearest Neighbor

MILD: Mnemonic Induced Lucid Dreaming

N1: Stage N1 Sleep

N2: Stage N2 Sleep

N3: Stage N3 Sleep

PSG: Polysomnography

RAM: Random-Access Memory

REM: Rapid Eye Movement

SSILD: Senses Initiated Lucid Dreaming

SVM: Support Vector Machine

WBTB: Wake-Back-To-Bed

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Chapter 1: Introduction

Heraclitus of Ephesus philosophized more than 2400 years ago about the phenomenon that waking and sleep connect and disconnect people from each other: people awake share one common world (*koinon cosmos*), whereas people asleep all turn to their own world (*idion cosmos*) (Heraklit, 1989). However, the *idion cosmos* and the *koinon cosmos* interrelate with each other: The *koinon cosmos* of all people awake can influence the dreams in the *idion cosmos* of a single person asleep, and the *idion cosmos* of a single person asleep can influence the *koinon cosmos* of all people awake. One example of this is a dream of the Egypt pharaoh Thutmose IV (~1500 BC), who slept as a young prince under the head of the Sphinx, which was buried up to the neck in sand. In his dream, the reign over the country was promised to him by the God of the Sun, Ra, if he freed the Sphinx from the sand. Thutmose IV fulfilled this task and became Pharaoh (Bryan, 1991).

However, up to today, the main characteristic of sleep is still commonly viewed as separating sleeping people from the wake world, as Stanford sleep scientist William Dement states: „The fundamental essence of sleep [...] is a disengagement from the outer world, accompanied by an engagement with the inner world and the dream world – that peculiar periodic consciousness in sleep. " (Dement, 1996)

This thesis aims at building a bridge between the wake world and the sleep world, connecting the two separated worlds, by developing "Sleep Communication": a method to communicate with a sleeping person. Communication thereby means sending arbitrary messages both from the wake world to the sleep world and vice versa from the sleep world to the wake world.

Why should a method to communicate with a sleeping person be developed? On the one hand, the idea to combine the enormous imaginary, creative and mental power of the dream world with the huge knowledge and technologies of the wake world seems very promising. Ideas might be born of which nobody could have ever thought or dreamed. Another answer is that sleep communication can be the basis of further technologies. Chapter 7 will describe some of these future prospects, and many of them seem to be reachable very soon.

This work is structured as follows: In chapter 2, the theoretical basics of sleep and dreams are summarized, and dream incorporations and the concept of lucid dreaming are described.

In chapter 3, the Theory of Sleep Communication is introduced, by defining what sleep communication is and describing the general principle of it. Moreover, the theoretical requirements for sleep communication are discussed in chapter 3, too.

In chapter 4, the theory is applied in practice. First, a technological framework for sleep communication – the Sleep Communication Framework – is created, describing with which hardware, software and interfaces sleep communication can be conducted. Second, a real-world implementation of this framework containing everything necessary for sleep communication is developed.

In chapter 5, an experimental pilot study is conducted in order to demonstrate that communication with a sleeping person, as described by the Theory of Sleep Communication, is possible using the Sleep Communication Framework and the real-world implementation described in chapter 4.

Chapter 6 summarizes the findings of this work and critically discusses the results.

Finally, chapter 7 completes this thesis with an outlook on future prospects regarding sleep communication.

SLEEP AND SLEEP STAGES

Sleep can be defined as "a normal, reversible and recurring state of reduced responsiveness to external stimulation which is accompanied by complex and predictable changes in physiology. These changes include coordinated, spontaneous, and internally generated brain activity […] and relaxation of musculature." (Encyclopædia Britannica Online, 2013).

In order to reliably distinguish sleep from being awake, the electrical activity of the brain, the eyes and the muscles have to be recorded (Dement, 1996). Brain activity can be measured using electroencephalography (EEG), eye movements using electrooculography (EOG) and muscle activity using electromyography (EMG). This procedure is termed polysomnography (PSG), and can include additional physiological parameters such as respiration recording or heart rate recording (Iber & American Academy of Sleep Medicine, 2007).

Figure 1: A polysomnographic recording including EEG, EOG and EMG conducted on the International Space Station (ISS)[1]

[1] Image source: http://www.redorbit.com/topics/polysomnography/

Using widely accepted rules on these physiological parameters, such as the *Manual of Standardized Terminology, Techniques and Scoring System for Sleep Stages of Human Subjects* (Rechtschaffen & Kales, 1968) or the newer *American Academy for Sleep Medicine Manual for the Scoring of Sleep and Associated Events* (Iber & American Academy of Sleep Medicine, 2007), it is possible to objectively classify not only whether a subject is asleep, but also different sleep stages that are common among humans. Objectively thereby means, that there is no interaction with or help from the subject needed.

The most obvious physiological parameter is the occurrence of rapid eye movements (REMs) measurable by EOG, dividing the human sleep into REM sleep and NREM sleep (not REM sleep). According to the scoring framework of the American Academy for Sleep Medicine (Iber & American Academy of Sleep Medicine, 2007), the NREM sleep can further be divided into three different sub-stages:

- N1 sleep (also called somnolence or drowsy sleep), which is characterized by predominant brain activity of 8-13 Hz (alpha waves) and 4-7 Hz (theta waves), sudden muscle twitches, hypnic jerks, sometimes hypnagogic hallucinations, and the lose of some muscle tonus;

- N2 sleep, which occupies about 45-55% of adult sleep time, characterized by specific brain activity patterns called sleep spindles (activity of 11-16 Hz) and K-complexes, and further decreased muscular activity;

- N3 sleep (deep or slow-wave sleep), characterized by predominant brain activity of 0.5-2 Hz (delta waves). Parasomnias such as sleep walking and sleep talking take place in this sleep stage (Pillar & Malhotra, 2002).

REM sleep was discovered in the middle of the last century by Aserinsky and Kleitman (1953). Besides its obvious rapid eye movements, it can be characterized by low chin muscle tone, transient muscle activity, low amplitude, and mixed frequency EEG, and sawtooth-like wave patterns in the EEG (Iber & American Academy of Sleep Medicine, 2007).

REM sleep shows typical properties of deep sleep (e.g., the subject is hard to wake), but also of wakefulness (e.g. similar EEG patterns). Thus, REM sleep is also called paradoxical sleep (Myers, 2004; Dement, 1998).

In a normal, undisturbed night sleep stages alternate between REM and NREM sleep. One so called cycle of NREM and REM sleep lasts approximately 90 minutes, prolonging towards the end of the night up to 120 minutes. The ratio of REM to NREM sleep varies during the night: At the beginning of the night, NREM and especially N3 sleep dominate, whereas in the last cycles of the night, long REM sleep periods dominate and there is nearly no N3 sleep (Billiard & Santo, 2003). Figure 2 shows an idealized illustration of the nocturnal sleep cycles.

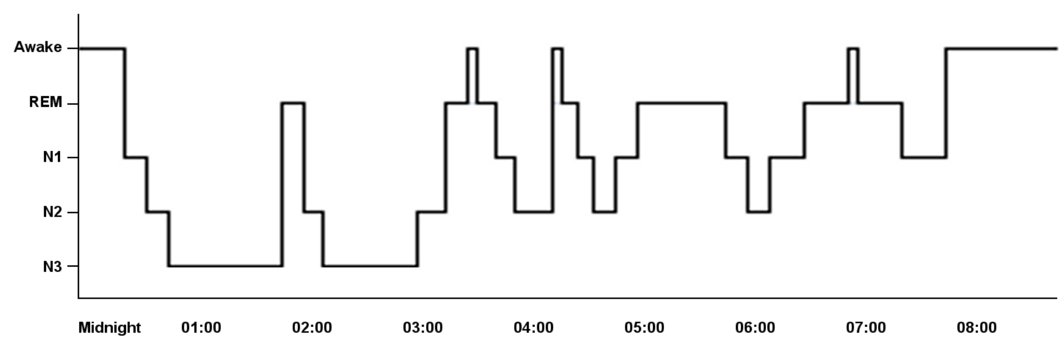

Figure 2: Idealized hypnogram showing the course of sleep stages throughout the night (own illustration)

DREAMING AND DREAM INCORPORATIONS

There is no single definition of what a dream is. One definition which shall be used here considers a dream as a recollection of the mental activity which has occurred during sleep (Schredl, 1999).

Research shows that dreams occur in all different sleep stages, but that the probability of dreaming varies with the sleep stage: Subjects waken up from REM sleep report in 70-95% of the awakenings from dreams, whereas only 5-10% of NREM sleep awakenings produce similar results (Dement & Kleitman 1957a; Dement & Kleitman 1957b; Hobson, 1988). Moreover, dreams occurring during REM and NREM sleep differ regarding the characteristics of the dream: NREM dreams mostly deal with thought-like experiences, REM dreams are more visual, image-like, more bizarre and are stronger related to the person of the dreamer – they are the "classical" dream (Foulkes, 1962; Antrobus, 1991).

In daily life, nearly everybody has experienced that stimuli from the wake world sometimes are built into ("incorporated") a dream – the famous alarm clock is only one example for this. Several studies have been conducted in order to examine how well different wake world stimuli are incorporated into dreams. Table 1 shows an overview on different stimuli and their incorporation rate.

Study	**Stimulus**	**Number of stimuli**	**Incorporation rate**
Dement and Wolpert (1958)	Sinus tone (1000Hz)	35	9%
Dement and Wolpert (1958)	Light flashes	30	23%
Dement and Wolpert (1958)	Water sprayed onto the skin	33	42%
Berger (1963)	Subject's name	45	40%
Koulack (1969)	Electric shocks at the thumb	99	56%
Hoelscher et al. (1981)	Neutral words	59	11%
Hoelscher et al. (1981)	Meaningful words	59	34%
Trotter et al. (1988)	Odor stimuli	79	19%
Nielsen et al. (1993)	Small pain stimuli	42	31%
Nielsen (1993)	Blood pressure cuff around the leg	28	87%
Leslie and Ogilvie (1996)	Rocking the hammock	45	25%

Table 1: Stimuli incorporations into dreams[2]

It can be seen that the results are mixed. Some stimuli show a high incorporation rate, as for example the blood pressure cuff around the leg by Nielsen (1993), some show only a low incorporation rate, e.g. the sinus tone in Dement and Wolpert (1958). However, one has to keep in mind that there are a lot of parameters involved and that this overview can thus only give a

[2] Source: Modified from Schredl (2006)

small hint on how well stimuli are incorporated, not an exact and precise comparison. Methodological parameters, as for example in which case to consider a stimulus as being incorporated, and confounding variables such as the choice of the subjects, lead to different study results, as well as parameters concerning the stimulus. For example, a change in the loudness of the sinus tone can lead to different incorporation rates, changing the brightness of light flashes as well, the amount of water sprayed onto the skin, the intensity of odor stimuli etc.

However, from studies such as Hoelscher et al. (1981) it can be seen, that similar but different stimuli such as neutral and meaningful words lead to clearly different incorporation rates, and that thus some stimuli seem to be better suited for being incorporated into dreams than others, and also, that there seems to be some processing of the stimuli during sleep by the brain.

Moreover, if one aggregates the numbers, tactile stimuli seem to be incorporated more often than others. Schredl (2006) suggests that such tactile stimuli might be treated differently by the brain than other stimuli since they might be phylogenetically more dangerous and important to the organism than others.

Another distinction regarding incorporation of stimuli into the dream world can be made between direct and indirect incorporations. If for example a sinus tone is played as a stimulus, it can be built into the dream directly, i.e. the tone as it is in the wake world appears in the dream but is not connected to the dream scenery, or indirectly, i.e. the tone is transformed into another sound fitting the dream environment better. One example from the experiments conducted for this thesis is a real world beeping tone which got (for the same subject) incorporated into one dream directly as is, into another dream indirectly as a beeping music in a discotheque.

PHYSIOLOGICAL (IN-) ACTIVITY OF THE SLEEPING BODY

During REM sleep, skeletal muscle movements are inhibited by neural structures in the brain stem so that dreamed movements are not acted out which could lead to severe injuries (Hobson et al., 2000; Jouvet, 1965; Pace-Schott, 2003).

However, the sleeping body is not completely paralyzed. Obviously, life preserving muscles like the heart muscle are still active, but of special interest in this thesis are movements of the eyes. According to the Scanning Hypothesis by Ladd (1892), eye movements show the same patterns during dreams as in wake life. There seems to be evidence for this hypothesis; it is however still unclear, how strong the relationship between dream eye movements and real eye movements is (Schredl, 2006; Arnulf, 2011).

Apart from eye movement, there are also other correlations between dreamed actions and physiological measurements of the sleeping body: for brain activity measured by EEG (e.g., Hong et al., 1996), limb twitches measured by electromyography (e.g., Gardner et al., 1975), and cardiovascular parameters (e.g., Baust & Engel, 1971).

LUCID DREAMING

A lucid dream is a dream in which the dreamer is aware that he or she is dreaming and is sometimes able to consciously influence the content of the dream (LaBerge, 1985). Some researchers extend this definition, for example Tholey (1985) who also considers aspects like clarity about the waking life as an indispensible prerequisite to call a dream lucid. In this thesis, I use the conventional minimal criterion for the definition (awareness of dreaming while dreaming).

A breakthrough in lucid dreaming research were the experiments by Hearne (1978) and LaBerge (1980a) in the late 1970s and early 1980s who showed that a lucidly dreaming person can give voluntary signals to the wake world using some muscle groups, for example by eye movements. The eye movements in lucid dreams largely correspond to the movements of the real eyes (supporting the scanning hypothesis mentioned before), which can be measured by EOG. These voluntary signals prove that the subject indeed knows during sleep of his mental state, and not only makes this up after awakening. Thus, it is possible to not only detect a lucid dream from the outside by dream report after the subject woke up, but to have the evidence that somebody is lucidly dreaming while this person is still asleep.

Besides movements of the eyes, other physiological parameters of the subject's sleeping body can be controlled from inside a lucid dream. These voluntary changes – including eye movements – are referenced to in the following as "body signals". Respiration can be voluntarily controlled during lucid dreaming as shown by LaBerge and Dement (1982a): breathing faster and stopping breathing inside the lucid dream was detectable by nasal airflow recordings. The EEG of a sleeping person can be influenced during lucid dreaming (Erlacher et al., 2003). Muscle twitches measured by EMG can - to some extent - be controlled from within a lucid dream (Fenwick et al., 1984). Another study by LaBerge et al. (1983) found a significant correlation between subjectively experienced sexual activity during REM lucid dreaming and several autonomic parameters such as respiration rate, skin conduction, vaginal EMG, and vaginal pulse amplitude. There was a significant increase of these parameters during experienced lucid dream orgasm, but surprisingly no significant increase in heart rate.

Lucid dreams occur typically, but not only, during REM sleep (LaBerge et al., 1981a; LaBerge et al., 1981b; Ogilvie et al., 1983; Fenwick et al.1984).

There are mixed findings in literature regarding the frequency and prevalence of lucid dreams. Studies show that lucid dreams are on average very rare, less than 1% of all dreams are lucid; however, among regularly lucidly dreaming subjects, 17.3% of the dreams recalled are lucid (Barrett, 1991; Zadra et al., 1992). Concerning the prevalence, some studies show a high number of subjects (82%) to have had a lucid dream at least once in a lifetime (e.g., Schredl & Erlacher 2004), some lower numbers (26%, Stepansky et al., 1998). A recent study in a representative German sample with 919 adults by Schredl and Erlacher (2011) found an overall prevalence rate of 51%. Erlacher (2010) suggests different sampling procedures and methodological differences between the studies as possible explanations for the mixed results. In a study by Voss et al. it was shown that lucid dreaming is much more prevalent in children and adolescents than in adults. (Voss et al., 2012).

Lucid dreaming is learnable (LaBerge, 1980b) and there exist numerous techniques and methods aiming at inducing a lucid dream. One arbitrary example for such a technique called "Senses Initiated Lucid Dreaming" (SSILD) is described in Appendix A. Unfortunately, no existing technique is able to reliably and consistently produce lucid dreams, even though some look promising (Stumbrys et al., 2012). As a result, until today lucid dreaming studies face the problem of finding qualified participants being able to produce a lucid dream, especially in the sleep laboratory environment, and thus often have to settle for small participant numbers (Strelen, 2006).

Lucid dreams can be investigated by sleep experiments. In a classical study design, participants perform actions which they have been asked to perform before going to sleep, and mark specific time points such as the time point of becoming lucid, the start of a task or the end of a task, by eye movements. One example for a classical lucid dream study answered the question, how long it takes to count to 10 in a lucid dream (approximately as long as counting in wake state) (LaBerge and Dement, 1982b), another exemplary study confirmed these results and, moreover, found that executing motor activities (performing squats) requires more time in lucid dreams than in the waking state (Erlacher and Schredl, 2004). Some studies demonstrate how to benefit from lucid dreams during waking life. For example, it is possible to train motor tasks during lucid dreams in order to increase the wake life performance of these tasks (Erlacher & Schredl, 2010).

Chapter 3: The Theory of Sleep Communication

DEFINITION

The Theory of Sleep Communication describes the method and its requirements by which it is possible to send messages with arbitrary content from the wake world to the sleep world and vice versa from the sleep world to the wake world, using dream incorporations, lucid dreaming, body signaling and a message coding scheme.

Sleep communication as described in this theory has to be distinguished from two related, but different phenomena. First, the term sleep communication describes the conscious, deliberate answering to messages by a sleeping person, and thus is different from subconscious reactions to stimuli during sleep. Second, sleep communication has to be distinguished from talking under hypnosis. As Spiegel and Spiegel (2004) write, these are two different mental states: "The hypnotized person is not asleep, but awake and alert." The Theory of Sleep Communication focuses on communication with sleeping people, not hypnotized people.

PREVIOUS WORKS

There have been previous works, upon which this theory is built. There have been numerous studies on sub-parts of the sleep communication as defined above, especially on wake world stimuli being incorporated into dreams, lucid dreaming in general and its capability to change physiological parameters of the sleeping body (see chapter 2). Even the idea of using some sort of message coding is not new: In a study focusing on sleep world to wake world signaling by LaBerge for instance, sleeping persons signaled single Morse code signs to the wake world (LaBerge et al., 1981a), another study by LaBerge (1993) reported attempts to communicate from a lucid dream to the wake world by using sign language, recorded by hand muscle EMG, but also stated that at least at the time these experiments were conducted, existing technology was not sensitive enough.

Some attempts have been made to combine lucid dream incorporations and body signaling, enabling a two-way exchange of signals. Strelen (2006) used a single high or low frequency tone to get incorporated into a dream, and used one predefined eye movement to signal back the detection of the high frequency ones. Oldis (2010) extends this in a theoretical manner by writing about the idea to use different stimuli cues and body signal cues for fixed messages like "I am dreaming" or "I am flying", possibly being put into the context of so called "multi-player dream games", i.e. multiple dreamers sending fixed cues to each other while lucidly dreaming. In experiments by Oldis and Oliver (2012) a simple light flash stimulus (light bulb on or off) and a predefined eye movement (looking twice to the right) were used for sending a signal from wake world to sleep world and back, and attempts to send a cue this way from one dreamer to another were claimed to have been successful once.

However, a scientific sleep communication theory combining lucid dreaming, dream incorporations, body signaling and message coding, and describing the requirements for the exchange of *arbitrary* and with *content filled* messages with a sleeping person, in both directions from wake world into sleep world and from sleep world into wake world, is still missing and shall be introduced here.

GENERAL PRINCIPLE

Messaging from the wake world to the sleep world works in principle as follows. A stimulus, for instance a blinking light, is presented to a sleeping and dreaming person. A message is coded into the stimulus using a coding scheme, for example the Morse code (see below). The stimulus gets incorporated into the dream, and is detected there by the dreaming person. The dreamer stays asleep and becomes conscious and aware of his sleeping and dreaming state by the stimulus, or was already aware of it before the stimulus incorporation. Finally, the dreamer decodes the message contained in the stimulus whilst still staying asleep.

Messaging from the sleep world to the wake world works very similar. The sleeping person selects a part or a physiological parameter of his wake world body which can be altered from within a dream, for instance the line of gaze of his eyes. The dreamer then again uses a coding scheme (which does not necessarily have to be the same as for the messaging from wake world to sleep world) and encodes a message into the body state alteration – short: gives a "body signal". In the wake world, the body signal is recorded, in this case for example by an EOG, and decoded by hand or by a machine.

THEORETICAL REQUIREMENTS

Requirements for Communicating from Wake World to Sleep World

The sleeping person has to be dreaming, and this needs to be detected from the wake world, in order to be able to incorporate stimuli into a dream[3]. Moreover, lucidity of the dreamer is necessary to ensure voluntary and conscious communication. It seems reasonable to use REM sleep as the preferred sleep communication sleep stage. Even though dreams can occur in all sleep stages, most dreams (and especially most lucid dreams) take place during REM sleep (see chapter 2). Thus, it seems reasonable to concentrate on REM sleep for sleep communication purposes in order to increase the probability for successful sleep communication. Presenting stimuli the whole night independently of the sleep stage does not seem promising, since there is a high chance of waking up the sleeping person, especially in the N1 and N2 sleep stages (compare the experiences from the experimental part of this thesis, chapter 5).

Second, the stimulus being used has to be able to contain (possibly encoded) information. It is not absolutely necessary to use words as a stimulus in order to have an information-containing stimulus. By using a coding scheme as for example the Morse code, also light flashes, sinus tones or even tactile stimuli can easily transport arbitrary information. Disadvantage of such a coding scheme is that the dreamer has to learn the scheme if he is not familiar with it.

Next, decoding the message from the stimulus has to be simple, so that the sleeper does not have to concentrate too hard on the decoding. Unstable dreams or awakening might be the result.

[3] The method could also be named "dream communication". But since the general term "dream" can also refer to day dreams of an awake person and this technique is explicitly about communication with a sleeping person, the term "sleep communication" is preferred over "dream communication".

Furthermore, the stimulus has to be of the right intensity. For example, auditory stimuli must not be too loud in order to not wake up the sleeper, but also not too quiet, because they might not be incorporated into the dream world then. A method to find a suitable intensity could be to start with a low value and increase the stimulus intensity step by step, until the sleeper either lucidly signals a dream incorporation or wakes up (in which case the intensity shortly before waking up can be taken as a threshold value).

Finally, the stimulus has to be easily detectable, even when being modified by the incorporation. A suggestion would be to use a stimulus of an exceptional, unusual kind so that the dreamer has no difficulties to keep track of the message. An exceptional stimulus might help the dreamer to become lucid, too.

Requirements for Communicating from Sleep World to Wake World

Obviously, it is important to select a body signal which can be accessed from within a dream, such as dream eye movements leading to movements of the real eyes, dream body muscle activity causing measurable activity of the real muscles, dream respiration affecting the real respiration, or selected tasks leading to specific brain activity (compare chapter 2).

Another important point is that the body signaling must not lead to waking up the sleeper. For example, using changes of respiration speed as a signaling method is not very practical as it directly influences the oxygenation level of the blood and thus might lead to waking up the sleeper.

Additionally, the mode of transportation has to be detectable from the wake world without affecting the sleep of the dreamer. For example, eye movements can be recorded by EOG, muscle movements by EMG, respiration by nasal airflow recordings and specific brain activation by EEG, functional Near-Infrared Spectroscopy (fNIRS), functional Magnetic Resonance Imaging (fMRI), or other techniques.

MESSAGE CODING SCHEME

For sending arbitrary messages from wake world and also from sleep world, a coding scheme can be necessary. A coding scheme here describes a system by which arbitrary content can be transmitted using a limited way of communication. Most of the stimuli which can be incorporated into dreams and can thus be used for messaging from wake world to sleep world, as for example sinus tones, light flashes or tactile stimuli, are limited in their variability and thus need a coding scheme. An exception is the use of spoken words; however, it is unclear how successful correct incorporations of these can be achieved. Equally, transporting arbitrary messages from the sleep world to the wake world using body signaling needs a coding scheme, too.

A very old coding scheme which can be used for this purpose and which needs only an ON-OFF capability of a stimulus or body signal, is the Morse code. The Morse code defines for each letter of the alphabet a sign consisting of short and long ONs, separated by short OFFs within a letter, longer OFFs between letters and even longer OFFs between words (see Appendix B). Moreover, there exist Morse signs also for punctuation and for numbers. Since this coding scheme only needs ON-OFF capabilities of a signal, it can be applied to a number of sleep communication stimulus types and body signals. Table 2 gives some examples. As can be seen, the same stimulus type or body signal can be used in various ways.

Stimulus type, body signal	**Short ON**	**Long ON**	**OFF**
Sinus tone	Short beep	Long beep	Stimulus muted
Sinus tone	High frequency beep	Low frequency beep	Stimulus muted
Light flash	Short light flash	Long light flash	Light turned off
Eye signal	Eye movement to the left and back to the center	Eye movement to the right and back to the center	No eye movement
Muscle signal	Contraction of left biceps, followed by relaxation	Contraction of right biceps, followed by relaxation	Relaxation of both biceps
Muscle signal	Short contraction of left biceps, followed by relaxation	Long contraction of left biceps, followed by relaxation	Relaxation of left biceps

Table 2: Morse coding scheme applied on exemplary stimulus types and body signals

It is also possible to use coding schemes with more than two different signs instead of using Morse code in order to increase the speed of coding. If for instance a stimulus type or body signal with six different variations is used, all 26 letters of the alphabet and the numbers from 0 to 9 can be represented by a combination of only two signs (instead of up to 5 Morse signs). Application examples are: light flashes in six different colors, or six different tones; eye movements to the left, right, up, down, in a clockwise circle and in a counterclockwise circle, or contractions of six different muscles. Disadvantage of such a more complex coding scheme is that it is harder to learn, and more difficult to control than using Morse code.

CHECKLIST FOR A COMPLETE SLEEP COMMUNICATION

To summarize the before mentioned, for a complete, successful sleep communication according to this Theory of Sleep Communication, ten points have to be fulfilled:

(1) The person to sleep communicate with has to be sleeping and dreaming, and this has to be detected by a dream sleep detector or by a body signal detector[4],

(2) playback of a stimulus containing a message, possibly encoded using a coding scheme,

(3) incorporation of the stimulus into the dream,

(4) lucidity of the dreamer,

(5) correct detection of the incorporated stimulus by the dreamer,

(6) correct decoding of the stimulus message if a coding scheme is used,

(7) comprehension of the message transported by the incorporated stimulus by the dreamer,

(8) heeding the incorporated message by the dreamer and thinking about a response,

(9) sending the response back to the wake world by encoding it into a body signal, and

(10) correct detection and decoding of the body signal by hand or machine.

Of course, this can be conducted repeatedly, leading to a dialog-like sleep communication.

[4] In case the sleeper uses a body signal to inform the wake world about his dreaming state, and if dream sleep is not detected by a dream detector.

Chapter 4: Sleep Communication in Practice 1: The Sleep Communication Framework

AIMS OF THE FRAMEWORK

After having introduced the Theory of Sleep Communication in the previous chapter, this chapter describes a way of bringing it into practice. Therefore, a technological framework – the Sleep Communication Framework (SCF) – is developed, which defines the technical requirements for a completely automated sleep communication: the hardware, the software and the interfaces by which these parts are connected and accessible. Furthermore, a sample real-world implementation is presented. This framework and its real-world sample implementation are finally tested in a pilot study (next chapter).

OVERVIEW OF THE FRAMEWORK

The SCF is structured in a modular way, as can be seen in Figure 3 on the next page. It contains everything necessary for a completely automated sleep communication as described in chapter 3: a device which can record sleep data, a device to generate stimuli, a device to record physiological or other parameters of the body suited for body signaling; a software module to detect dreams or at least REM sleep using the sleep recording device, a software module which can control the stimulus generating device and can code information into the stimulus using a coding scheme, a software module which can detect and decode body signals; a software module enabling user interaction and connecting the other software modules, possibly a data visualization software module, and possibly an action output software module which can be used to control arbitrary other software or hardware using sleep communication. These modules are described in more detail below.

A main priority when designing the SCF was laid on exchangeable and extendable modules. For example, it should be possible to use a different device for recording of sleep data with having to make only minor connectivity changes in the dream detection software modules, all other modules should not be affected by this. Similarly, e.g. the software for detecting and decoding body signals should be easily interchangeable, allowing to try out and to compare different implementations or algorithms easily. Lastly, due to its modularity, it is also possible to use the SCF in a semi-automated way: for example, if a stimulus is used which cannot be controlled by a computer, the stimulus generation module can be filled out by human action.[5]

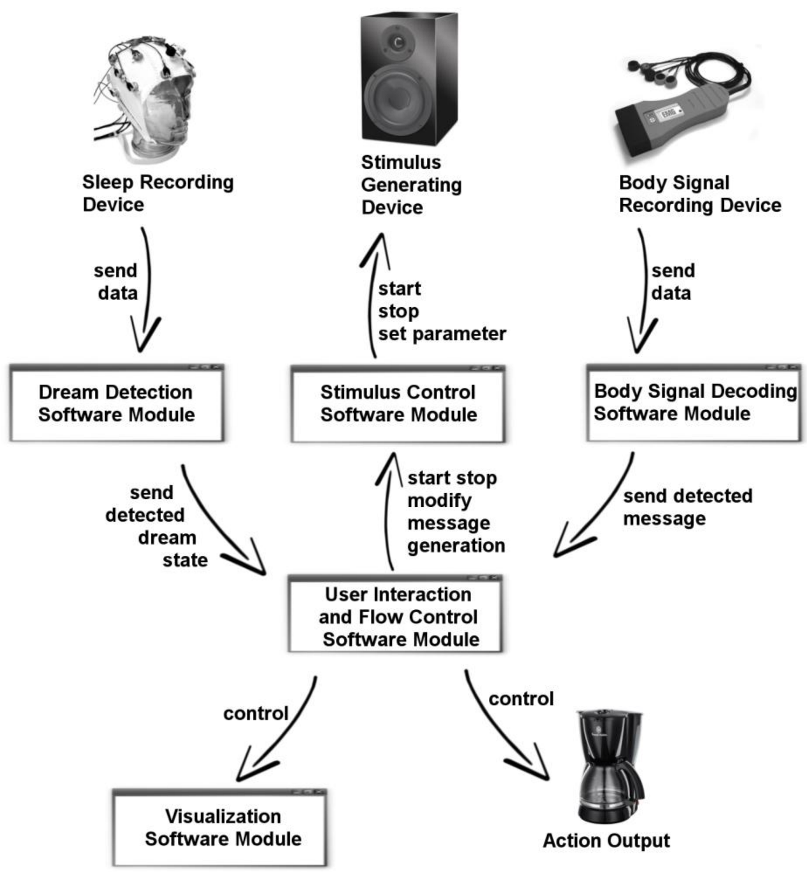

Figure 3: Schematic illustration of the Sleep Communication Framework

[5] In theory, it could even be possible to conduct sleep communication completely anti-automated without any electronics involved: rapid eye movements can be detected by just looking at the sleepers closed eyes, a lucidity signal using changes of the respiration could also be detected without electronics, a stimulus could consist of spoken words, and as a body signal again an intelligently coded respiration rate change would make sleep communication very impractical, but theoretically possible without any electronics.

HARDWARE COMPONENTS OF THE SLEEP COMMUNICATION FRAMEWORK

Sleep Recording Device

A device capable of recording data that allow the detection of dream sleep is needed, such as an EEG system or even a system containing multiple devices such as a real polysomnographic system with EEG, EOG and EMG. As suggested by the Theory of Sleep Communication, it seems reasonable to use REM sleep as the preferred sleep communication sleep stage (compare chapter 3). Depending on the device(s) used, the REM detection reliability varies: using only a cheap one-channel EEG, there will be more misclassifications than with a professional complete polysomnographic system.

Stimulus Generating Device

A device for producing stimuli is needed. Depending on the choice of the stimulus, this can be speakers (for auditory stimuli), a computer screen or computer-controllable LEDs bright enough to lighten the room with an intensity noticable through closed eyes (for visual stimuli), tactile devices, or other.

It is also possible to use multiple stimuli simultaneously, which might increase the incorporation probability and communication speed on the one hand, but on the other hand might also lead to premature awakenings.

Body Signal Recording Device

A device capable of recording messages from the sleep world is necessary, for example an EOG or EMG recording device. In practice it might be a feasible idea to use the same device as was used for sleep recording: If for example an EEG system is used as a sleep recording device, it can be possible to find body signals in the EEG data without having to implement another device. These body signals can even be of different nature than the ones used for REM detection, for example eye movement artifacts in the EEG signal.

Again, it is possible to use multiple parallel body signal types, in order to increase the speed of communication.

Computer

Not shown in Figure 3, but obviously necessary, is a computer to run the software connecting and controlling the hardware devices. The computer requirements depend on the hardware and software components used: A real-time REM detection using a 128-channel EEG cap and sophisticated data post-processing needs a better computer than a sleep recording device which might even classify the sleep stages on its own and just transmits the result.

SOFTWARE COMPONENTS OF THE SLEEP COMMUNICATION FRAMEWORK

Sleep Recording Device Connection and Dream Detection

This software module determines whether the sleeping person is dreaming or not, and sends this information to the user interaction and flow control module.

Depending on the device used, two scenarios are possible: a) the device or its provided software detect REM sleep automatically; in this case this software module has to read out the current REM state from the device or its software and send it to the user interaction and flow control module, or b) the device or its software do not detect the REM sleep automatically; in this case this software module has to access the (raw) data generated by the sleep recording device and apply a self-programmed REM detection algorithm on them, which can be of various kinds, e.g. using artificial neural networks.

Advantages of a self-programmed REM detector are that its parameters can be modified to one's own needs, that it is understandable ("white box" instead of "black box"), and that it can be individually programmed according to a specific person's sleep. A possible advantage of a device shipped with a predefined REM detector could be that this way the expertise of the device's manufacturer can be used.

Stimulus Generating Device Connection and Stimulus Control

The stimulus control module receives commands from the user interaction and flow control module, which it has to implement. Therefore, this software module has to build up a connection to the stimulus generating device. Moreover, it has to implement a way of message coding into the stimulus using a coding scheme. Lastly, this module has to provide a facility to start and stop the stimulus, and to change stimulus parameters (e.g. the stimulus' intensity).

Body Signal Recording Device Connection and Body Signal Decoding

This module is very similar to the dream detection module. It detects body signals in the data of the body signal recording device, and then decodes them.

Again, depending on the device used, two scenarios concerning body signal detection are possible: a) the device or its provided software detect body signals automatically; in this case this software module has to read out the current body signal state from the device or its software and send it to the user interaction and flow control module, or b) the device or its software do not detect the body signals automatically; in this case this software module has to implement a body signal detection algorithm, which can be of various kinds, e.g. using support vector machines.

Again, an advantage of a self-programmed body signal detector is that its parameters can be modified to one's own needs, is understandable ("white box" instead of "black box"), and can be individually programmed according to a specific person's body signals.

User Interaction and Flow Control

This module implements the logic of sleep communication and connects all other software modules. It integrates the information coming from the REM detection module and the body signal detection and decoding module. Moreover, it implements rules on when and how to start, stop or modify the stimulus generation. One example for such a rule can be a waiting time: Only if out of the last *m* seconds at least *n* % have been classified as REM sleep, stimulus generation is started, otherwise stopped. This way, a false REM detection due to noise in the data does not switch the stimulus on or off immediately. Another exemplary rule can be a stimulus control mechanism using the body signal detection and decoding: If a specific body signal is detected, stimulus intensity is decreased.

Moreover, this module offers a possibility for user interaction, allowing the user to control stimuli and their parameter directly, to set parameters of REM detection or body signal detection and decoding, or to access the data visualization. This can be implemented in a graphical user interface providing simple use of mouse and keyboard.

Data Visualization

This module is not absolutely necessary for sleep communication, but can offer valuable information to the user by giving the user the ability to look at the data of the sleep recording device and the body signal recording device in real-time. The visualization can show the raw data as is, or apply filters or other transformations on them before. The user can verify this way that the automatic REM detection and the automatic body signal detection work correctly.

Action Output

This module is not absolutely necessary for sleep communication. It extends the SCF by adding the opportunity to control arbitrary other software or hardware with sleep communication. This can be basically anything, from steering a Quadcopter to sending commands to a Raspberry Pi. For example, this powerful option could be used to control a coffee machine[6] from sleep using automatic body signal decoding, letting it wake up the sleeper by the smell of fresh coffee.

CONNECTIONS BETWEEN THE SOFTWARE MODULES

There are basically three ways, how the software modules can be connected.

First, there is the all-in-one solution, meaning that all software modules are combined in one application. This is the easiest and fastest way to implement, since all software modules can directly call methods from other modules (e.g., start of stimulus generation) and can access the data of all other software modules directly. However, if hardware devices are used which do not offer open access to their data but only the use of proprietary manufacturer software, an all-in-one solution might not be possible. These parts of the SCF implementation would then have to be excluded from the all-in-one solution and be accessed in another way. Moreover, the easy interchangeability of single module implementations by other, better implementations is not

[6] http://www.raspberrypi.org/archives/4217

given anymore when using a all-in-one solution. Furthermore, if one software module crashes (e.g. data visualization), all other modules might stop working, too (depending on the concrete implementation).

Second, all software modules could run separately, avoiding the disadvantages of the all-in-one solution at the expense of a more complex development, since this implies that the software modules have to communicate with each other: for controlling each other and for exchanging data. For instance, the software module for REM detection could send its data (the current REM status of the sleeper) to the user interaction and flow control module, which determines according to a rule (e.g. a waiting time rule) whether the stimulus generation should start, and then eventually sends a command to the stimulus generation module.

There are several ways on how to implement such a module communication, for example by storing the relevant information in a file or database, by using shared memory, socket programming and many more. All these connection types have their benefits and disadvantages; the interested reader is referenced to the specialized literature, e.g. Akhter and Roberts (2006).

Third, a middle way between the all-in-one solution and the complete separate implementation could be chosen, by combining some of the modules into one software implementation.

ONE IMPLEMENTATION OF THE SLEEP COMMUNICATION FRAMEWORK: THE SLEEATOR 2

In this chapter, one real-world implementation of the SCF is presented, including all of the SCF's requirements for a completely automated sleep communication.

The software of this implementation is called "Sleeator 2", which is a short version for "SLEEpCommunicATOR". The version number is 2 already because the software architecture and design were completely reprogrammed from scratch during the development process in order to improve the performance.

Hardware devices used are the Zeo (for details, see below), and ordinary speakers (see below).

The main purpose of the Sleeator 2 developed here is to supply a real-world implementation to enable the user to communicate during sleep. The Sleeator 2 includes all necessary technologies for automated communication both from wake world to sleep world and from sleep world to wake world: a real-time REM sleep detector, a stimulus generator for sending messages from wake world to sleep world, a real-time eye movement detector and message decoder and a graphical user interface for setting all necessary parameters such as the stimulus intensity.

Moreover, it includes additional tools and settings for recording, visualizing, simplifying and optimizing the process of sleep communication, such as: direct recording of EEG data to a SQL database preventing data loss, a replay mode for recorded data, a simulation mode for simulating a signal for testing purposes, automatic live visualization tools for the raw EEG data and its Fourier transform including multiple adjustable filters, adjustable and trainable machine learning algorithms (k-nearest neighbor, feed-forward artificial neural network, support vector machines, threshold classifiers and more) for REM detection and eye movement message detection, the possibility to use multiple REM and/or eye movement message detectors simultaneously, logging possibilities, automatic stimulus playback with modifiable REM waiting time and other adjustable parameters, advanced stimulus control such as stimulus pausing for x seconds capabilities, an action interface allowing to execute various commands according to the detected eye movements messages such as stimulus control.

Since the Sleeator 2 is equipped with automatic REM detectors, automatic stimulus generation methods and automatic eye movement detectors, it is possible to use the software for completely automated sleep communication on one's own and for self-experiments without the need for additional people around. Of course, sleep communication with a computer as implemented by the Sleeator 2 might not be as interesting as with a human, but for future applications of sleep communication this might be an interesting feature (compare chapter 7 on future prospects).

The software consists of several thousand lines of Python code (without the imported standard libraries). It would thus go beyond the scope of this thesis to describe the whole software or its code in detail. Hence, the description below will focus on the most important features of the software. For more details, the interested reader is referred to the code directly which is attached on the DVD. In case of unclarities of what an element in the GUI is useful for, there have been implemented extensive tool tips for many GUI elements, so hovering about an unclear element with the mouse will give additional information on its function, too.

The Sleeator 2 is structured into different tabs. The first tab deals with connection to the recording, visualization of the raw signal and of its Fourier transform, and offers a database reset option. The second and third tabs enable the user to modify, retrain and save the REM and eye movement detectors. On the fourth tab, details for sending messages from wake world to dream world can be specified, and similarly, on the fifth tab, details for messaging from sleep world to wake world.

If all necessary Python libraries are installed and the Zeo is connected to the computer, starting a sleep communication is very simple, as illustrated in Figure 4 and Figure 5.

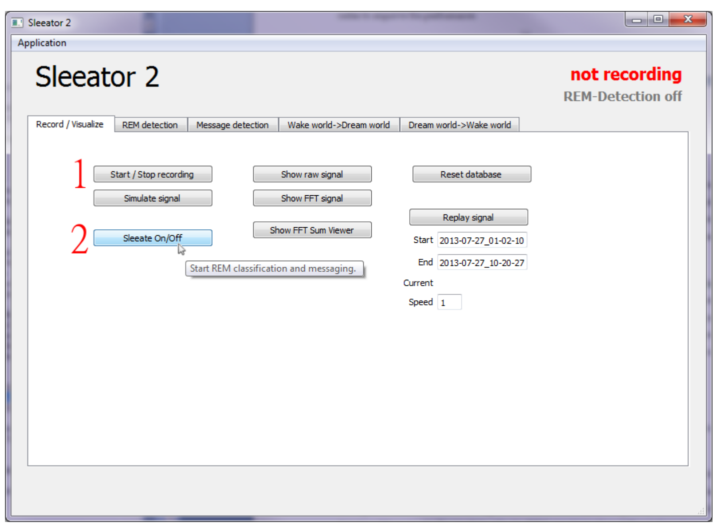

Figure 4: In order to sleep communicate, only the recording has to be started (1) and the automatic sleep communication using the predefined settings has to be started (2).

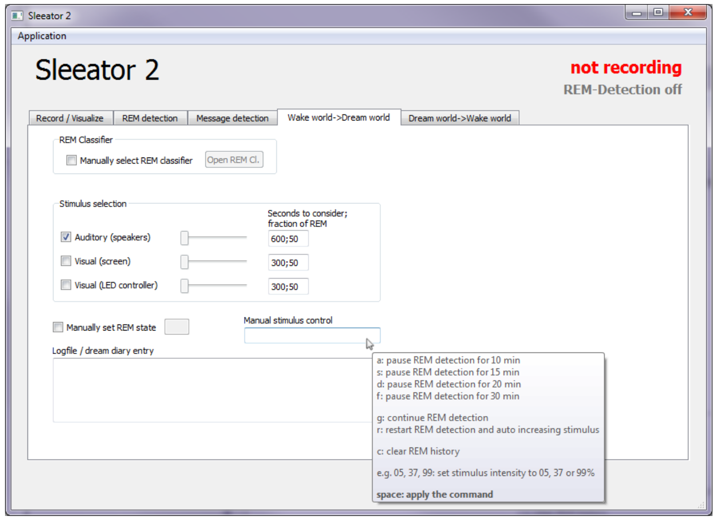

Figure 5: Additional parameters, e.g. the waiting REM time until stimulus generation is started, or the stimulus intensity can be set on the other tabs.

Connection to the REM Detection Device

The REM detection device used in this implementation is the Zeo[7], a wireless headband with three prefrontal electrodes, which are combined into a one-channel 128 Hz EEG signal. The raw signal is accessible with a time lag of less than 2 seconds, allowing nearly real-time REM detection. Moreover, the Zeo itself classifies the EEG signal into three different sleep stages or the awake stage, and can thus be used as a direct REM detector, too. It is connected via serial cable to the computer and sends once every second the raw EEG data and other metadata such as timestamp and the Zeo's sleep stage classification to the computer.

There is an official open source Zeo library for processing the Zeo data which is used and was heavily modified by the author for the Sleeator 2. The Zeo library is modified so that the incoming raw signal, its Fourier transform, a notch-filtered version of the raw signal, Zeo's detected sleep stage and metadata are saved directly into an SQLite[8] database once every second. The recording can be started and stopped from the Sleeator 2 GUI and runs in a separate thread for better performance. The focus when developing the Zeo-Sleeator 2 connection was laid on

[7] Produced and sold by Zeo Inc. (went out of market in May 2013).

[8] http://www.sqlite.org/

data security, so that even if the program crashes, windows shuts down due to power saving options or other unforeseen problems, the data up to this point are stored on hard disk safely.

Data Visualization

The raw signal can be plotted in real-time and selected frequencies can be filtered out. Moreover, a real-time time-frequency plot showing the fast Fourier transform (FFT) over time can be displayed. In this data visualization, the plotted data can be filtered using freely specifiable kernels, e.g. allowing Gaussian window averages or simple averages. Additionally, a choice between logarithmic and linear plot scale can be made, there is an automatic artifact removal option and more.

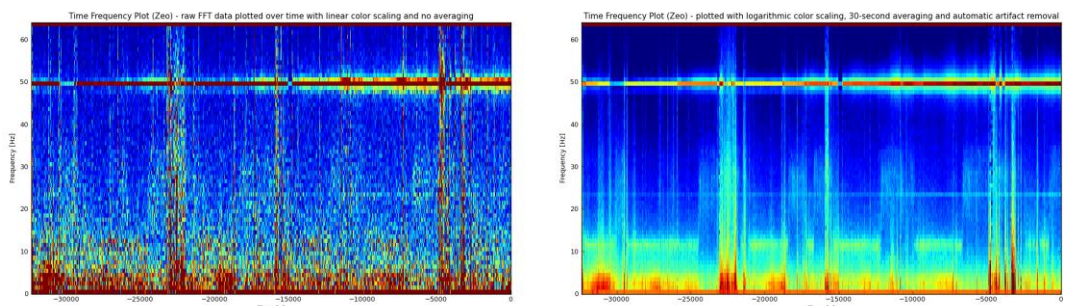

Figure 6: Comparison of two time frequency plots of the same night obtained with the Sleeator 2 using different filters and plotting settings. Recurring sleep patterns can be easier detected in the post processed plot.

REM Detection and Individual Training of REM Detectors

There are two main kinds of REM detection applicable with the Sleeator 2: First, REM detection using external devices and classification, such as the Zeo's internal REM detection, and second, REM detectors using the raw data or its transformations.

As described above, advantages for the first way are that it is easy to use, needs less resources on the computer for classification, and offers a buy-in of external experience (e.g. from Zeo's manufacturer). Benefits of the second variant are that it is individually trainable for each subject, adjustable according to one's own wishes, understandable ("white box" instead of "black box") and can be further developed.

A REM detector can be selected on the fourth tab. It is also possible to use multiple classifiers simultaneously. Figure 7 to Figure 11 demonstrate how to train an own REM classifier.

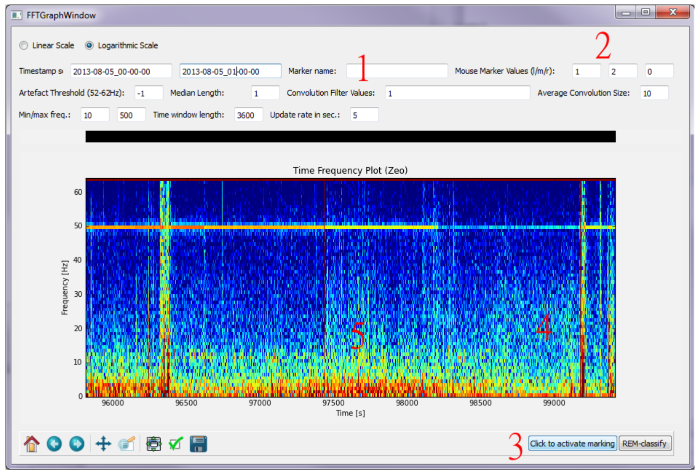

Figure 7: For training a new REM classifier, first a name has to be specified with which the training data are named (1). After having specified class names with which the training data can be associated (2), the user can mark data in the plot by draging the mouse over it (3, 4, 5). Depending on the mouse button used for dragging, the corresponding classes are assigned to the data.

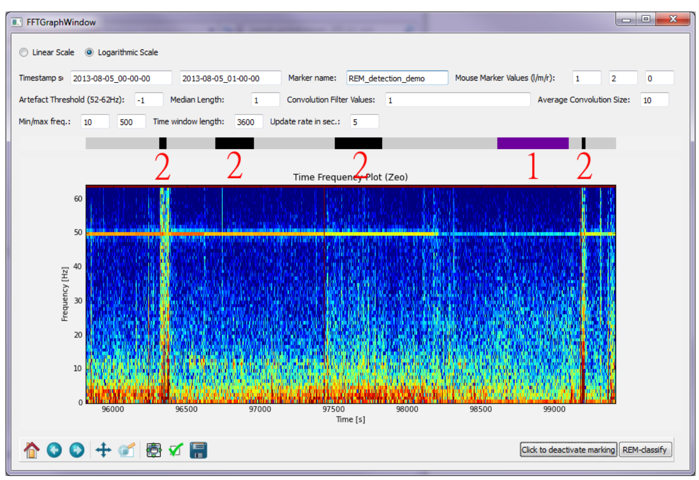

Figure 8: The classes assigned to the data are automatically plotted in color above the time frequency plot, here class "1" for REM in purple (1) and class "0" for NREM in black (2).

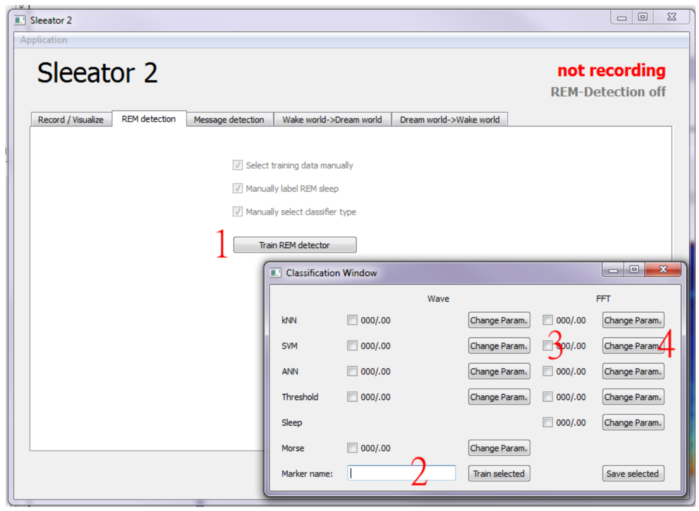

Figure 9: On the second tab, a new REM detector can be trained (1). For doing so, a set of training data has to be chosen (2), a machine learning algorithm has to be selected (3), and eventually further parameters can be set (4).

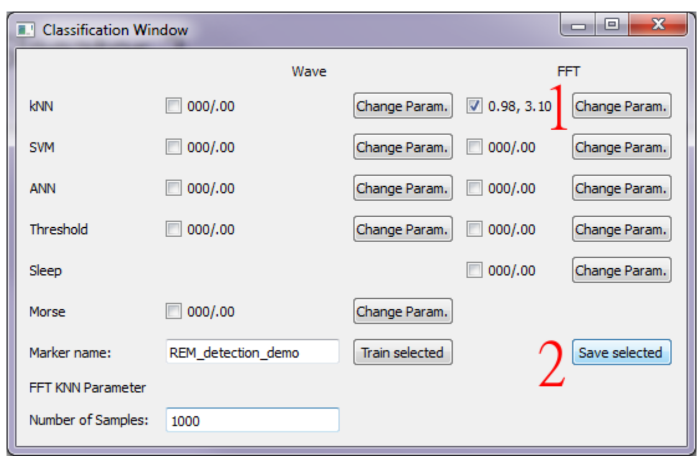

Figure 10: After training the classifier using n-fold cross validation (here: k-nearest neighbor algorithm), the performance and the time needed for training are displayed (1), and the selected REM detector can be saved (2).

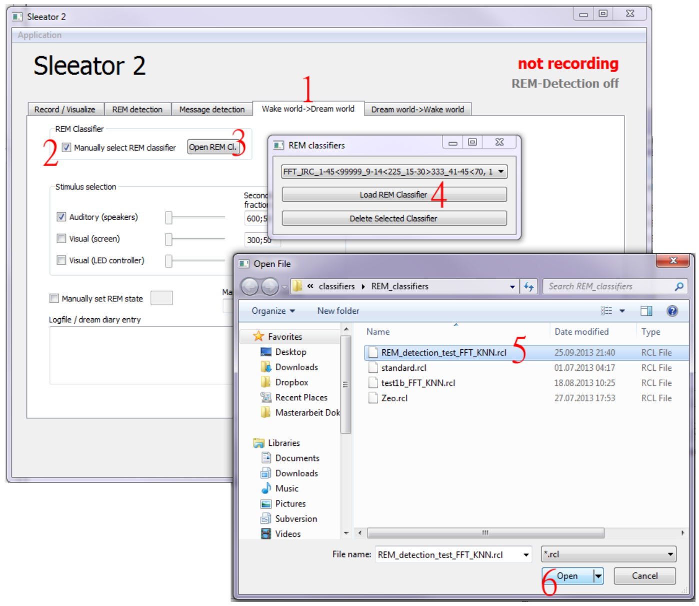

Figure 11: Finally, on the fourth tab of the Sleeator 2 (1), a custom REM classifier can be selected (2, 3, 4, 5 and 6) for detecting REM.

There exist numerous machine learning classification algorithms (for an overview, see for example Kotsiantis et al., 2007). In Sleeator 2, three different "standard" algorithm types can be used to build a REM classifier: support vector machines, artificial neural networks, and a k-nearest neighbor classifier. These supervised learning algorithms are programmed to make use of n-fold cross validation. Two more classifier types who simply use thresholds of specific frequency bands as REM detection criterion are also available. After training, the trained classifier and its parameters can be saved into an *.RCL file (RemCLassifier file).

Body Signal Detection, Training and Decoding

Since the Zeo is used as a REM detection device in the Sleeator 2 and its raw prefrontal EEG signal shows large eye artifact, these eye artifacts can be used for messaging from sleep world to wake world. Consequently, there is no extra device or connection necessary, since the same device as for REM detection is used for eye movement detection.

The process for training an eye signal detector is very similar to the REM detection process. However, instead of using the Fourier transform of the EEG signal, the raw signal itself should be used. Again, support vector machines, artificial neural networks, and a k-nearest neighbor classifier are available for detecting and decoding messages using eye movements.

Stimulus Generation

The Sleeator 2 offers the option to select auditory as well as visual stimuli. As described in the SCF, the stimuli do not necessarily have to be produced immediately when REM sleep is detected. In Sleeator 2 such waiting time thresholds can be entered freely. Moreover, in case of multiple simultaneously selected stimulus types, different thresholds for each stimulus type can be selected, such that it is possible to first start the visual stimuli, and some time later start with the auditory ones. Doing so, one can start the incorporation trials with a stimulus type that has a low risk of waking up the sleeper but a low incorporation rate, too, and later on add more "risky" stimuli. Combining this with the stimulus control described below, the sleeper could stop starting the "risky" stimulus in case of an early stimulus incorporation and lucidity.

In order to not wake up the sleeper directly, stimulus intensity should either be set to a value below waking threshold, or, if this threshold is not known, be started with a very low intensity and then be increased over time. Using this auto-increase method, stimuli might get incorporated at some specific intensity level and the sleeper has the possibility to stop the increase of stimulus intensity by making use of stimulus control with his eyes, as described below. Both auto-increasing stimuli and static stimulus intensity are built-in features of the Sleeator 2.

Action Output

The eye movement detection and decoding can be coupled to an action output. As described in the SCF, an action output can basically be anything programmable. An obvious action output example can be a stimulus control. The Sleeator 2 offers the feature of controlling the stimulus using eye movements and Morse code as follows: Looking three times to the left (Morse code: three times short, thus a Morse "S") (re)starts generating a stimulus with auto-increasing intensity. This is helpful in case the sleeper is lucid, but the REM detector has for some reason not detected REM sleep or the waiting time threshold is not reached yet. Equivalently, Morse code "O" (three times right) would stop stimulus generation. In case the sleeper experiences dream instabilities or has the fear of waking up because of the stimulus, this option can be a way of solving the issue. Additional stimulus control options implemented into the Sleeator 2 are the fixation of stimulus intensity to the currently used value in case of auto-increasing stimuli intensity ("M", two times right) and the decrease of stimulus intensity ("T", two times left). However, qualifying the before mentioned, these action outputs have been tested only briefly during wake state and not yet during a real sleep communication.

Chapter 5: Sleep Communication in Practice 2: An Experimental Pilot Study

In order to test whether the Theory of Sleep Communication and the Sleep Communication Framework implemented by the Sleeator 2 can lead to a successful sleep communication, several experiments have been conducted.

There have been self-experiments conducted by the author of this thesis as well as experiments with independent subjects ("non-self-experiments").

CHALLENGES

There were several challenges that had to be faced for the experimental part of this work. First, it was difficult to find subjects who are frequent lucid dreamers. The better the lucid dreaming abilities of the subject, the higher the probability that sleep communication can be conducted in the experiment. Finding lucid dreamers was especially difficult since the experimental phase of this project took place in the middle of the semester break, when only few students were available.

Second, the concept of conducting a polysomnographic study in a sleep laboratory was new to the author and thus had to be learned for these experiments. This included conducting experiments in a sleep laboratory in general, putting on the EEG cap, EOG and EMG electrodes, calibration and recording, sleep stage classification using the rules given by the AASM Manual (Iber & American Academy of Sleep Medicine, 2007) and data post-processing.

Third challenge was that the company producing the Zeo, Zeo Inc., went out of business during the development of the Sleeator 2 and similar alternative products were not available. Thus, an originally planned experimental phase with several subjects wearing Zeo's simultaneously in order to increase the number of nights recorded could not be conducted. Moreover, wear parts like the silver-iodized dry EEG electrodes could not be replaced since they were not sold anymore. Additional measures like special cleaning of the dry electrodes had to be adopted in order to ensure a sufficient signal quality.

EARLY SELF-EXPERIMENTS DURING THE DEVELOPMENT PROCESS OF THE SLEEATOR 2

Aims

The first self-experiments were conducted during the development process of the Sleeator 2. The aim of these early exploratory experiments was to find out what is necessary for sleep communication, what the difficulties and challenges are and how to overcome them. Additionally, gathering practical experiences on this new technology was an aim of these early experiments, too. Lastly, debugging and further development of the software were also important goals of the early self-experiments.

Methods

The early self-experiments were conducted at home and (rarely) at the Virtual Reality laboratory at the University of Osnabruck, for trying out a specific stimulus generation technique (see below). There were in total approximately 40 nights recorded.

Figure 12: LED half circle with 111 individually controllable LEDs. The bed was placed were the chair stands. Stimulus intensity was controlled by the number of LEDs turned on, their color and their brightness.

The subject of the self-experiments (the author of this thesis) was a 26-yo male student of Cognitive Science, a relatively experienced lucid dreamer with irregular lucid dreams (on average 2 per month, approximately 25 lucid dreams in total before beginning of the self-experiments).

The REM sleep and eye movement recording device used in these experiments was the Zeo, a wireless headband with three prefrontal electrodes, which are combined into a one-channel 128

Hz EEG signal. The signal was sent to a docking station which was connected by cable to a computer.

The early self-experiments consisted mainly of incorporation try-outs with the following stimuli: sounds of a bell, LED half-circle (see Figure 12), sinus-tones and computer screen.

Results

The data of the early self-experiment nights were useless for any sort of advanced statistical analysis, since the experimental settings, the recording data structure and the stimuli tried out changed steadily due to continuous development of the software and methods. Nevertheless, there were still several (rather subjective) experiences gathered and lessons learned. The most important of these can be summarized as follows:

- Many of the recorded nights revealed bugs and malfunctioning of the software, for example the need to not store the night's sleep data in RAM but on hard disk. Storing the data in RAM led to severe performance issues especially at the end of the night (the data alone reach magnitudes of up to a Gigabyte for one night). Moreover, Windows power options and Windows updates shutting down the computer after some hours or program crashes during the night led to data loss, if data were stored in RAM.

- The time-frequency plot of Zeo's EEG signal showed distinct patterns, corresponding to the Zeo's sleep stage classification. Taking also sleep stage features of the AASM manual (Iber & American Academy of Sleep Medicine, 2007) into consideration, as for example large delta wave activity for N3 sleep or sleep spindle activity for N2 sleep, sleep stages can be classified with the Zeo's raw data at least up to some degree. A more detailed analysis including comparison to parallel polysomnographic recordings are describes below.

- An idea which came up during the early self-experiments was to simplify the sleep communication process by excluding the REM detection step and to play the stimuli during the whole night instead. During the early self-experiments this option was tested with visual light stimuli (the LED half-circle), and, later, with acoustic stimuli. The effect observed was that the sleep quality suffered dramatically due to the following reasons: a) falling asleep with ongoing stimulus presentation is much harder, b) stimulus generation leads to numerous awakenings during the night, especially during the light sleep periods and after micro-awakenings when turning around. As a result, continuous stimuli played throughout the night are not considered to lead to advantages for sleep communication.

- Starting stimulus generation immediately after REM detection led to the problem that the dreams of the sleeper were just about to start and no complete dream scenery was built up in which the stimuli could be incorporated. Thus, a waiting period before stimulus generation was found to be useful.

- Using auto-increasing stimulus intensity leads to the problem that the intensity increases until the sleeper wakes up. This problem can be solved by implementing a stimulus control for example with eye movements with which the sleeper can modify the stimulus intensity from within the dream.

- In order to prevent dreaming of a non-existent stimulus and thinking it was a real incorporation, a random factor could be used in order to make it impossible to know beforehand what message is sent into the dream world and to be able to distinguish between made-up and real incorporations. One possible solution: random, computer generated numbers transformed into stimuli via Morse code make it impossible to know beforehand which number to expect. Thus, if dreaming of a stimulus and the dream report reveals another number as generated by the computer, sleep communication was not successful. This idea can be extended in such a way that the sleeper directly answers the random number back to the wake world using eye movements, so that is becomes clear that the sleeper knew about the incorporation and identified it as being a message from the wake world. Another further extension would be to include a simple transform of the stimulus, so that the response of the sleeper is improbable to be automatic and subconscious due to extensive training during wake state. This idea was used in the further experiments (see below).

SELF-EXPERIMENTS AFTER IMPLEMENTING THE MAIN FUNCTIONALITY OF THE SLEEATOR 2

Aims

The aim of these pilot study self-experiments was to produce at least one successful sleep communication as defined by the Theory of Sleep Communication with the Sleep Communication Framework and the Sleeator 2 as its implementation – a classical proof-of-concept that the idea of sleep communication works. As stated in the Theory of Sleep Communication, for a successful sleep communication ten requirements have to be fulfilled:

(1) The person to sleep communicate with has to be sleeping and dreaming, and this has to be detected by a dream sleep detector or by a body signal detector, (2) playback of a stimulus containing a message, possibly encoded using a coding scheme (here: a random math problem), (3) incorporation of the stimulus into the dream, (4) lucidity of the dreamer, (5) correct detection of the incorporated stimulus by the dreamer, (6) correct decoding of the stimulus message if a coding scheme is used, (7) comprehension of the message transported by the incorporated stimulus by the dreamer, (8) heeding the incorporated message by the dreamer and thinking about a response, (9) sending the response back to the wake world by encoding it into a body signal, and (10) correct detection and decoding of the body signal by hand or machine (here: an eye movement signal).

Methods

The self-experiments took place at home (first seven nights) and in the sleep laboratory of the NeuroBioPsychology department at the University of Osnabrück (last two nights).

The sleep communication was conducted according to the Sleep Communication Framework with the Sleeator 2 as its implementation.

The hardware device used for sleep recording and eye movement recording during the first seven nights was the Zeo (like in the early self-experiments). During the last two nights, when sleeping in the sleep laboratory, polysomnographic (PSG) recordings were conducted additionally to the Zeo recordings using a NeuroScan amplifier and software system. This system recorded 19 channel EEG (according to the 10-20-EEG system as depicted in Appendix D), horizontal and vertical EOG and chin EMG. Impedance was kept below 5 kΩ. Data was sampled at 500 Hz.

REM sleep was detected by two systems: by the Zeo's intern sleep stage classification on the one hand, and on the other hand simultaneously by a threshold REM detector optimized for the sleep of the subject. This self-programmed classifier took three frequency bands of the EEG of one second (9-14 Hz, 15-30 Hz, and 41-45 Hz) into consideration and if the sum of the frequency values in each band was below (9-14 Hz, 41-45 Hz) or above (15-30 Hz) a given threshold, it classified the second accordingly as REM or NREM. The frequency bands and thresholds were determined by analyzing the course of different frequencies for the subject over several nights, and identifying different patterns in the frequency bands of the subject's sleep. One of these patterns was assumed to correspond to REM sleep (basically because the frequency values corresponded to the AASM manual's rules (Iber & American Academy of Sleep Medicine, 2007) and the Zeo's intern classification showed REM sleep, too). Both REM sleep detection systems were used simultaneously, i.e. if at least one of the two systems detected REM, the Sleeator 2 assumed that the subject was in REM sleep.

Stimuli were played if out of the last 300 seconds at least 50% were classified by at least one system as REM sleep.

Computer generated sinus tones with a frequency of 1000 Hz played by Logitech S-120 speakers were chosen as stimuli. A simple random math problem (two random one-digit numbers had randomly to be added or subtracted) was encoded into the sinus tones using Morse code. Examples can be found in Figure 13 and as an *.mp3 file on the DVD. The stimuli were played using the auto increment feature of Sleeator 2 for the stimulus intensity, increasing the loudness of the tones form 10% to 100%. 100% were set to match approximately twice the loudness of surrounding noise (i.e. at home noise of the computer and the street outside, and in the sleep laboratory noise of the computer, the ventilation system and the polysomnographic recording system).

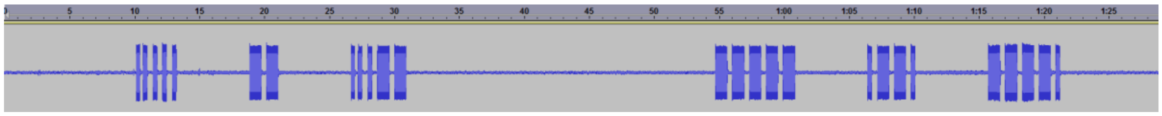

Figure 13: Example for an auditory stimulus (1000 Hz sinus tone ON or OFF) containing a Morse coded message: 5 short tones ("5"), two long tones ("M", minus), three short and two long tones ("3"), resulting in the math problem "5-3"; and accordingly the second math problem, "0+9".

The eye movement chosen to signal lucidity was “look five times to the left (and in between back to center)”. This signal is different to the left-right-left-right signal normally used in lucid dreaming research but was chosen in order to make it easier to detect in the Zeo EEG.

Results

General Statistics

During the 9 nights recorded, 23 dream reports could be obtained. There were four lucid dreams in total, and two direct and four indirect incorporations of the stimuli into the dreams. One complete successful and two partly successful sleep communications could be conducted.

Excursion: Comparison between Zeo Data and Polysomnographic Recording Data

It is not the aim of this thesis to compare the data obtained by different sleep recording devices in detail. Nevertheless, since it will be necessary in the further discussion of this thesis to know how comparable data of the Zeo and a polysomnographic recording are, a brief comparison is done here.

It does not seem plausible to compare noise levels of the systems, since the Zeo device used was quite worn but the electrodes could not be replaced due to the business failure of Zeo Inc. (as described above). Thus, noise in the EEG data from the surrounding, e.g. 50 Hz noise from power supplies, had a stronger effect on the used Zeo electrodes than it would have had for a new Zeo headband.

The comparison is based on the simultaneous Zeo and PSG recordings of one exemplary night (total recording duration: 8 hours = 28800 seconds).

Whole Night Time-Frequency Comparison

If one plots the Zeo's raw data in a time frequency plot using the Sleeator 2's visualization module, one obtains a colorful picture as is illustrated in Figure 14, first and second plot. In the first plot the fast Fourier transform of the signal for each second is shown. For each second (x-axis) the plot shows the power of a given frequency (y-axis) using a color scheme in which warm colors indicate high amount of the frequency in the signal of the given second and cold colors indicate low power. For example, at second 4000 there was a high amount of 3 Hz frequencies, but only few 60 Hz frequencies in the signal. The 50 Hz line is a noise artifact from nearby power supplies. The vertical lines are artifacts which might result from movements during the night. The second plot averages the data of the first plot over sliding 10 second windows. As can be seen in plot 2, there are reoccurring patterns in the data, for example in the low frequencies (0-4 Hz). This will be discussed in more detail below. The third plot in Figure 14 shows the results of different REM detectors: the Zeo's REM classification for this time period (first row) and also the classification of a self-programmed threshold classifier (2nd row: classification based on the Fourier transformed data of each second, 3rd row: averaged classification based on the rule: "classify a given timepoint as REM if 50 % or more of the previous 30 seconds are single-second REM", other rows accordingly). Purple color indicates "REM detected", the blue colored time period at the beginning if the rows illustrate the length of the considered time period. As can be seen, the Zeo classifier detects REM more or less according to specific sleep patterns, especially of relatively high 15-30 Hz frequency band activity and low 10-14 Hz frequency band activity. The Zeo's REM detection is based on 30 second intervals. Moreover, as can be seen in the second row, if no summation is applied, i.e. the single second determines whether to start/stop a stimulus, this leads to much disrupted REM detection and as a result, to the stimulus being turned on and off all the time, without the chance to send a complete math problem for example. Using a waiting period can avoid this effect, as can be seen for instance for the "50 % out of 300 seconds" rule. Increasing the percentage of minimum single-second REM classification obviously leads to less REM detection in total, as can be seen in rows 4-6.

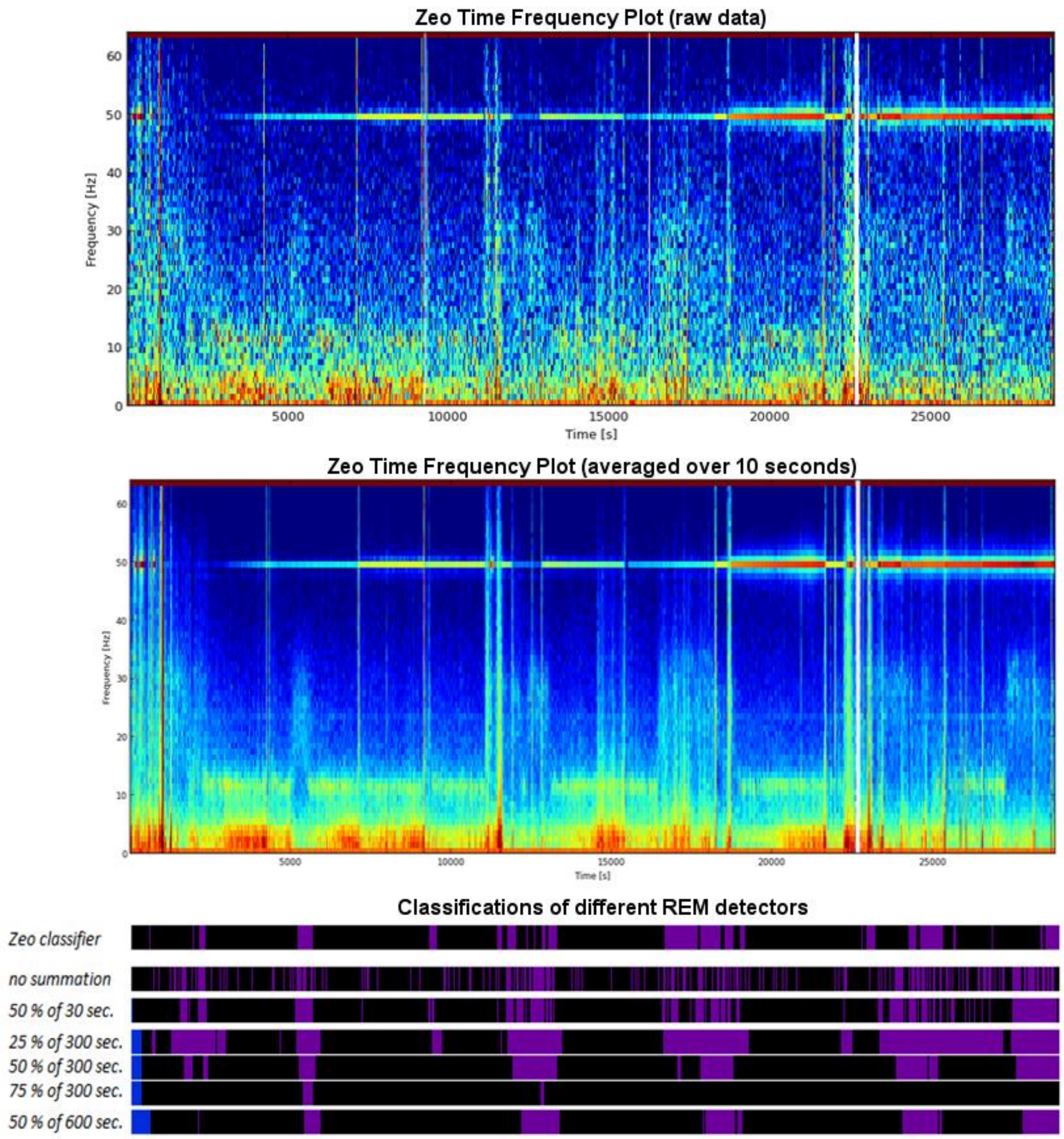

Figure 14: Classification of the Zeo's Fourier transformed data by different REM detectors (further descriptions in the text)

If one compares the frequencies plotted over time of the Zeo and simultaneously recorded selected PSG channels, it becomes visible that (not surprisingly) their time-frequency plots look similar (see Figure 15). Especially the prefrontal electrodes (e.g., FP1), which are very close to the Zeo's electrodes, detect very similar EEG frequencies throughout the whole night. For an overview on the exact positions of the electrodes on the head, see Appendix D.

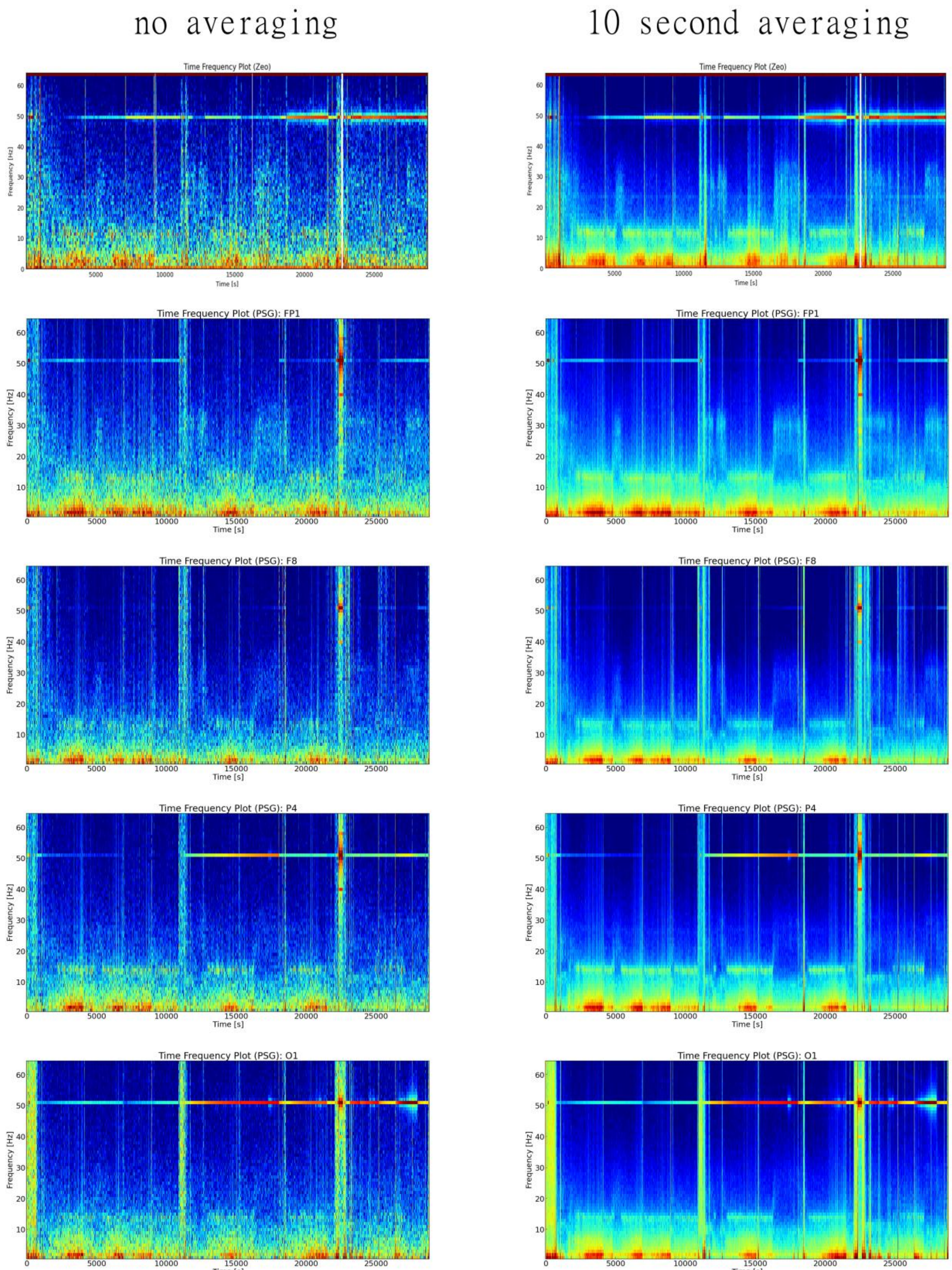

Figure 15: Comparison between time frequency plots obtained by the Zeo (first row) and a PSG (other rows), raw data and averaged over 10 seconds.

Patterns in the Zeo's Data and Possibly Corresponding Sleep Stages

One characteristic in both the Zeo's and the PSG's EEG frequency data are the periods with strong slow wave (0-4 Hz) activity. These recur throughout the night, but can predominantly be found in the first half of the night, for example around 6330 seconds after start of recording. Having a closer look at the PSG data of this time point (an example is given in Figure 16), it is visible that this period can be easily classified as N3 sleep due to the predominant delta waves. The Zeo EEG clearly shows the slow waves, too. Even though it is problematic to generalize from this one example to all other occurrences, it seems plausible that if there is large slow wave activity in the Zeo's data, and the Zeo's data correspond in the frequency domain largely to the PSG data (as demonstrated above), that there are slow waves measurable also in the PSG and thus, N3 sleep seems probable during periods showing this pattern in the Zeo frequency domain.

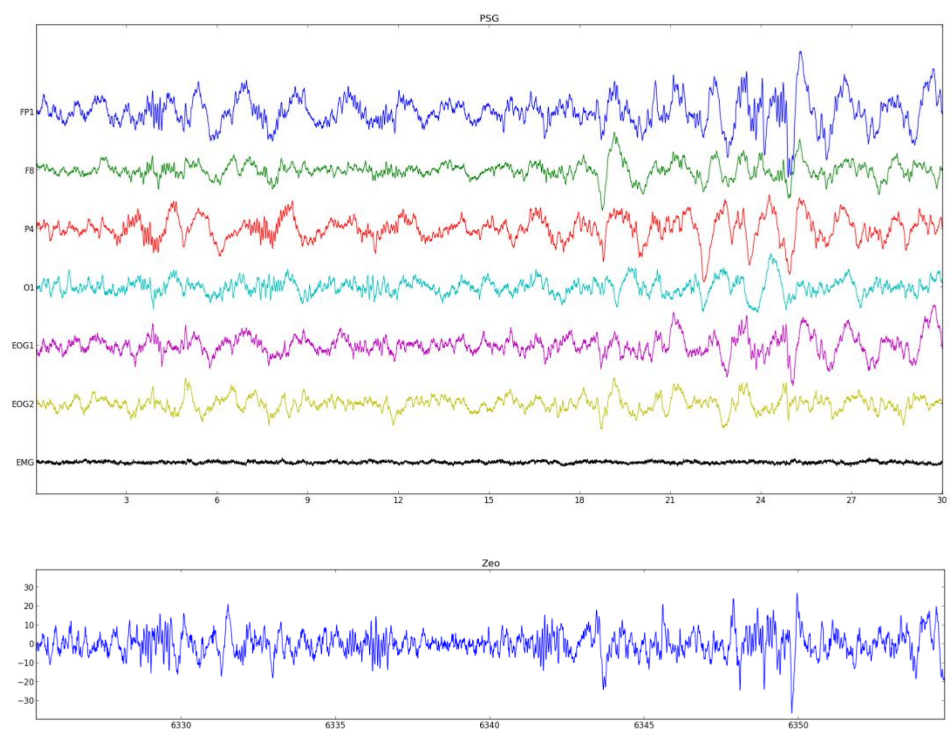

Figure 16: N3 sleep simultaneously recorded by PSG (top) and Zeo (bottom)

Another recurring characteristic pattern both in the Zeo's data and the PSG data are sleep spindles at around 10-13 Hz and the K-complexes, a clear sign of sleep stage N2 if there are only few slow waves. Figure 17 shows these patterns as for example found in both Zeo's data and the PSG data around 10170 seconds after start of recording. Especially the time-frequency plot makes it easy to identify these sleep spindles in the Zeo's data as the sleep spindles occur as little short, dot-like patterns in the 10-13 Hz frequency band.

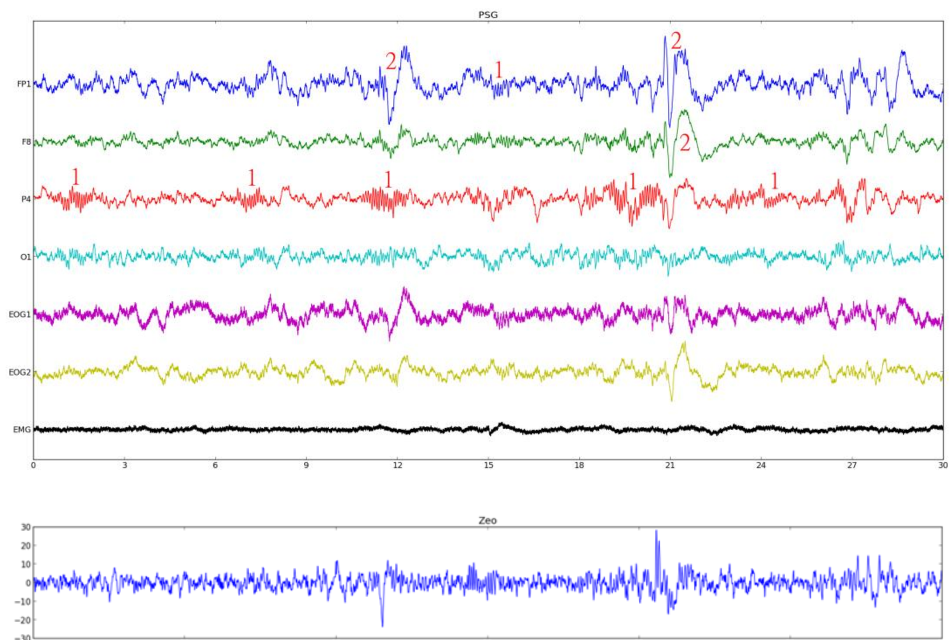

Figure 17: N2 sleep simultaneously recorded by PSG (top) and Zeo (bottom), showing sleep spindles (1) and K-complexes (2).

Then there are periods during the night with very low alpha band (8-13 Hz) activity and simultaneous high beta and gamma band activity (especially between 20 and 35 Hz), for example at 5190 seconds after start of recording. During this period, REM sleep can be classified using the PSG data due to the "butterfly" EOG data/rapid eye movements, the low amplitude mixed frequency waves, low amplitude EMG and the sharply contoured sawtooth waves. See Figure 18 for details. The Zeo's raw data are displayed for comparison.

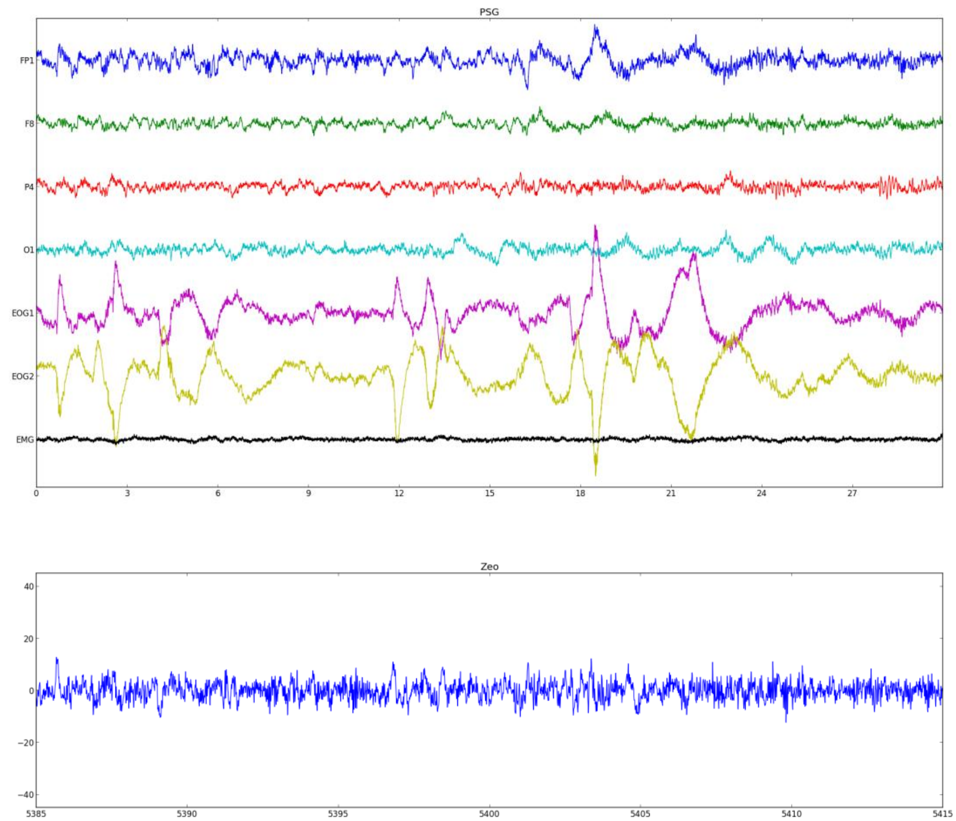

Figure 18: REM sleep simultaneously recorded by PSG (top) and Zeo (bottom)

During the periods with high activity in all frequency bands, but especially in the high (>35 Hz) frequencies, the person is obviously awake, as these patterns can be found for example at the very beginning of the night when the subject is still awake.

Besides these obvious patterns there might be others which cannot be identified as easily.

SUMMARY

In this excursion it was shown that the Zeo's EEG data correspond broadly to the data of a PSG – at least in the frequency domain. Additionally, recurring patterns can be detected in the Zeo's sleep data, especially when looked at in the frequency domain. It is possible to use these patterns to obtain some information about the sleep stage the subject is probably in at that time, as was shown by comparing the Zeo's data to the data of a PSG at the given time periods. Of course, this is not a proof that the person definitely is in the specific sleep stage, but can give at least a strong hint. For proving that a person is in a certain sleep stage (or awake) PSG is necessary. Also other studies on this topic agree that it is to some extent possible to identify sleep stages from the Zeo's data (Shambroom, 2012; Griessenberger 2013).

Successful Sleep Communication

During the seventh night, a successful sleep communication was conducted. The dream report written down immediately after awakening, and before having looked at any recordings or logs, states the following (translated from German into English):

"It was a very discombobulated dream. I stood in front of a furniture shop, looking at the display of kitchens and kitchen furniture. It was quite dark. I became lucid there somehow, but unfortunately do not remember how. I knew immediately about the sleep communication I wanted to conduct, and gave the lucidity signal (looking five times to the left). There were no tones incorporated, so I tried to find them somewhere hidden in the dream world. I walked along the street (alone), until I reached some sort of bus terminal. I had the feeling that the dream was not very stable, so I tried to stabilize the dream by interacting with the dream world using my hands since I experienced this method to have been helpful for dream stabilizing in other lucid dreams. But there was nearly nothing I could do with them. Eventually, a passerby appeared, and I told him about the lucid dream and that I would want to stabilize it, so we ended up clapping each other's hands, like in kindergarten. This lasted at least 30 seconds. Then the dream was stable. I next looked out for possibilities to get signals from the wake world incorporated into the dream, or better: I looked for something that was able to beep. Then I saw a ticket machine (still being at the bus terminal). Suddenly there was a beeping tone, but I think it did not come from inside the ticket machine, but was "just there somehow". I was thrilled to bits. I stayed dreaming, did not awake. Still being at the bus terminal, I decoded the first message, confirmed some of the numbers, solved the math problem, and answered it back to the wake world. 4+4=8. I next walked along the street further, telling other pedestrians that I was solving tasks within a lucid dream, and started listening to the next math problem. I don't remember whether I could answer this one, it was something with 5 minus… I believe. Then the dream stopped, maybe I had light sleep then? Did not wake up. Later on there was another dream, a concert with my accordion orchestra at Theater Wedel. It was directly before the concert started, somehow I could not read the set list with the songs we were about to play – it was reflecting very much. Some members of the orchestra were there, too. In the audience were some of my family members. Then, an abrupt scenery change, breakfast with my family. There were rolls which had been warmed up in the oven, a poppy-seed roll. Then I woke up. "

The sleep data recorded by the Zeo are displayed in Figure 19 - Figure 23. In Figure 19 the complete sleep communication is depicted, from the lucidity signal to the body signaling, and also the continuation of sleep after the sleep communication dream ended. From the data it can be seen that with a very high probability the subject was in REM sleep, since the Zeo EEG signal consists of (in comparison to other sleep stages) high amplitude 20-35 Hz frequencies, but no dominant 10-14 Hz frequencies as they would be characteristic for N2 and N3 sleep. Moreover, there is only low activity in the frequencies >35 Hz (apart from the 50 Hz power supply artifact), which makes it very unlikely that the signal was recorded during an awake phase.

The timing of the math problem ("4+4") fits the timing of the body signals very well. Directly after the first number "4" was sent, the body signal "4" was answered, as was stated in the dream report as "confirmed some of the numbers", too. After the math problem was completely transmitted, the body signal answer occurs directly in the data, which is not very surprising since the calculation of 4+4 is not very complicated. Also the beginning of the next math problem ("5-") fits the dream report, and the artifact occurring directly after the minus might explain, why the sleep communication was stopped there, and why the dream scenery changed so abruptly. However, there is no light sleep, as was stated in the dream report, the time frequency plot shows nearly no change in comparison with the sleep communication period. It remains unclear, why the subject had the impression to have stopped dreaming.

The EEG eye movement artifacts coding the answer of the math problem "4+4" into a body signal are shown in Figure 23. Especially in the repetition of the answer, the second "8", the eye movements can be clearly seen. The eye movement to the right has been stronger than the eye movement to the left, but it is unclear, why.

The Zeo data provide a very strong "hint" that the subject had REM sleep, but no proof. As mentioned in the excursion, a PSG recording has to be conducted in order to state doubtlessly that the sleep communicating person was indeed sleeping. Nevertheless, this is the maximum evidence one can get from the Zeo's data for the person wearing the Zeo headband to have been asleep and sleep communicating, and moreover, the dream report corroborates this finding.

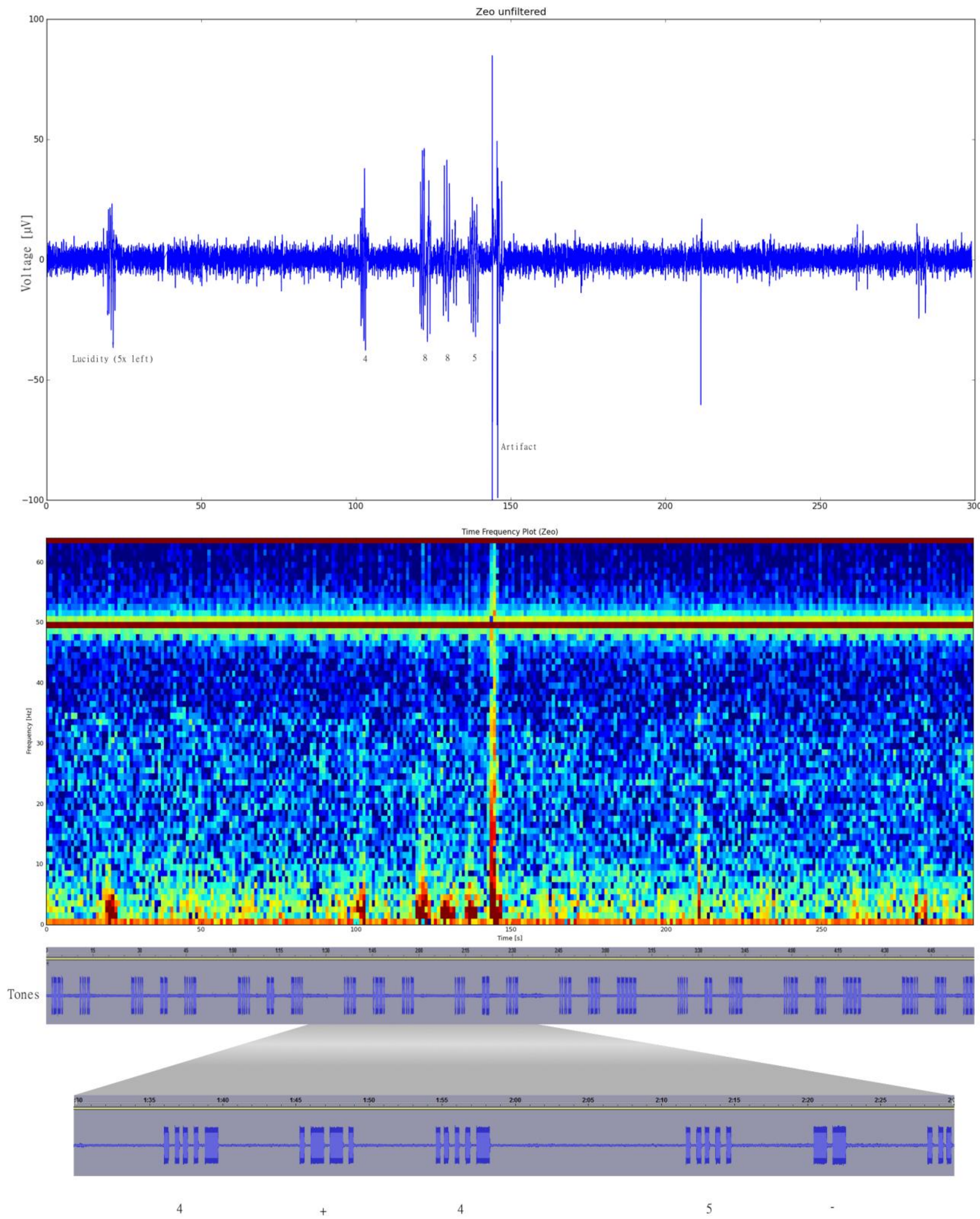

Figure 19: Overview of the complete successful sleep communication: Lucidity signal at second 19, tones of the math problem solved ("4+4") between seconds 95 and 119, repetition of the first decoded number ("4") at second 101, correct answer to the math problem ("8") at seconds 120 and 128, repetition of the first number ("5") of the following math problem ("5-4") at second 136, artifact (probably due to body movement) at second 143.

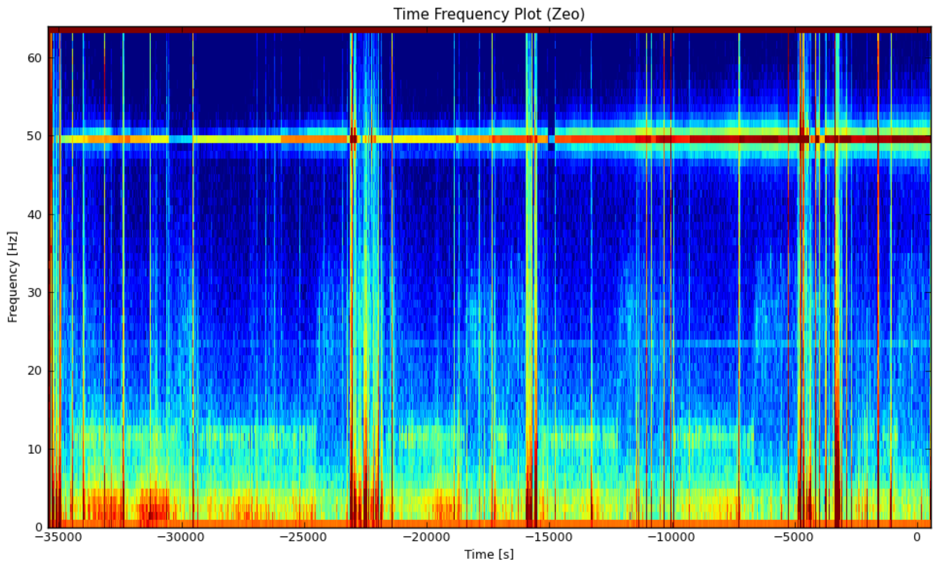

Figure 20: Complete night recording in which the sleep communication occurred (10-second averages are plotted). The x-axis numbering is kept consistent with the other plots for making comparison easier. The sleep communication took place briefly before the end of the night.

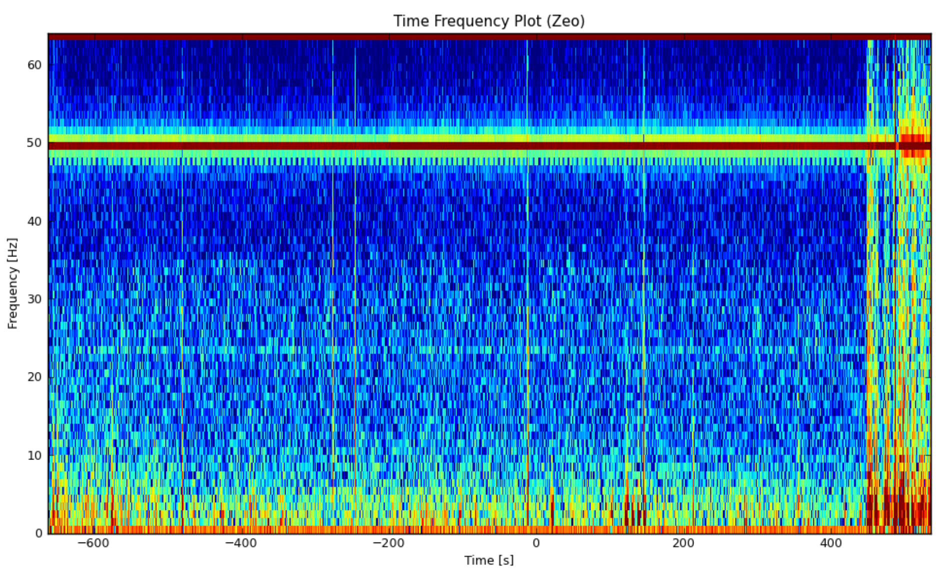

Figure 21: The last 20 minutes of recording. Again, the successful sleep communication is visible around second 120.

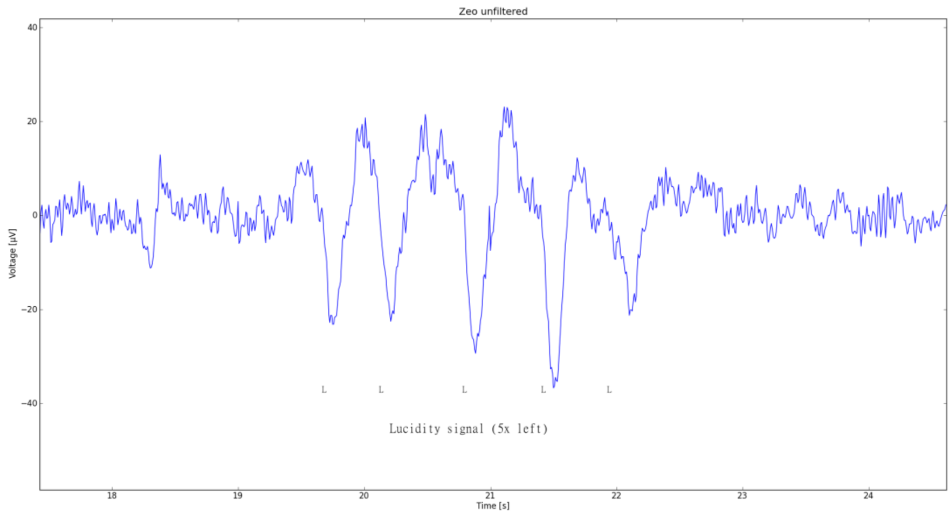

Figure 22: Detailed illustration of the lucidity signal: Looking five times to the left (and back to center in between), giving five clearly visible up-and-down eye artifacts in the EEG signal.

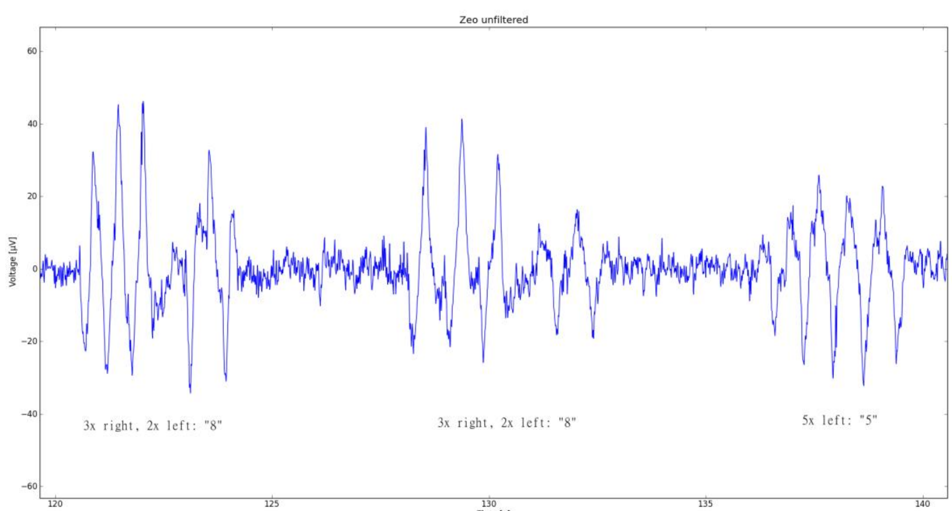

Figure 23: Detailed illustration of the correct answer to the math problem (three times right (down-and-up) and two times left (up-and-down): "8", sent twice by the dreamer), and the first number of the following math problem ("5").

As stated above, for a successful sleep communication several points have to be fulfilled according to the Theory of Sleep Communication, which shall be checked briefly:

(1) The person to sleep communicate with has to be sleeping and dreaming, and this has to be detected by a dream sleep detector or by a body signal detector: REM was detected using the Zeo's intern sleep stage classifier and a self-programmed threshold classifier, which correctly detected dream sleep (see dream report and Zeo's EEG data in Figure 19 to Figure 21).

(2) Playback of a stimulus containing a message, possibly encoded using a coding scheme: Multiple random math problem were coded into 1000 Hz sinus tones and were automatically played, as can be seen in Figure 19.

(3) Incorporation of the stimulus into the dream: At least one complete math problem and a part of the next math problem were incorporated directly into the dream as beeping tones, which at first seemed to originate from a ticket machine within the dream, but continued being present even when moving away from the ticket machine.

(4) Lucidity of the dreamer: Lucidity could be held for approximately 124 seconds and was signaled using the stipulated lucidity signal: looking five times to the left.

(5) Correct detection of the incorporated stimulus by the dreamer: The dreamer detected the stimulus (after having actively searched for it) coming from a ticket machine.

(6) Correct decoding of the stimulus message if a coding scheme is used: The dream report states that the subject correctly decoded "4+4" from the stimulus signal, and the dreamer did not report any difficulties in decoding the stimulus message. However, due to the self-programmed and tested stimulus generation, there was a lot of training involved before this sleep communication, especially as this dream took place during one of the last nights of the self-experiments.

(7) Comprehension of the message transported by the incorporated stimulus by the dreamer: The dreamer did not report any problems in understanding the message, which was not very

difficult since he knew what type of message to expect (a math problem) and the message was held very simple ("4+4").

(8) Heeding the incorporated message by the dreamer and thinking about a response: The dreamer did not report any difficulties with calculating the answer, which might have been due to the simplicity of the task.

(9) Sending the response back to the wake world by encoding it into a body signal: The dreamer encoded the answer ("8") into eye movements using the Morse code as a coding scheme, which was agreed upon before going to sleep: Long tones of the Morse code were coded into body signals as looking to the right, short tones of the Morse code as looking to the left. The dreamer looked three times to the right, and two times to the left, which means Long-Long-Long-Short-Short, Morse code for "8". Again, the dreamer was quite trained in generating this kind of body signals, as it was (involuntarily) tested during software development multiple times.

(10) Correct detection and decoding of the body signal by hand or machine: The eye movements were recorded as eye artifacts by the Zeo EEG, as can be seen in Figure 23. The decoding was conducted by hand after awakening.

Since all of the ten requirements for a successful sleep communication, as given by the Theory of Sleep Communication, were fulfilled, it can be concluded that sleep communication took place and thus, is indeed possible.

Two Incomplete Sleep Communication Attempts

Two more partly successful sleep communications could be conducted. Both took place during the first nights of the self-experiments, before the successful sleep communication. These nights are briefly described in order to point out some more experiences made.

During the first of these dreams, the written dream report states that the subject dreamed of lying inside his own bed, and became lucid by recognizing that the ceiling of the room was far closer to the bed than in reality. The dream continued as moving around in the flat, giving lucidity signals (five times looking to the left) twice, and one left-right-left-right signal, which could be detected in the Zeo EEG data, too. After meeting Albert Einstein, who did not respond to any communication attempts, incorporations of tones were looked for. There were no tones incorporated into the dream, since no REM sleep was detected by the REM detectors and thus, no stimuli were played. A stimulus control, enabling the dreamer to start stimulus presentation from within a dream using body signals, was not implemented at this time point. Thus, it can be concluded from this dream, that an active stimulus control by the dreamer is useful in order to increase the chances for sleep communication.

During the second of these dreams, the subject wrote down the following dream report (translated from German into English):

I swam, under the water, Pacific [ocean] southwards. I was bodyless, was drifting, round Cape Horn. I was lucid the whole time. I heard some news in the background, something about soccer. I breathed under water after realizing that I would drown otherwise. There was a very strong drift, no chance to swim against it, did not try it. Then there were [very loud] tones, I struggled hardly not to wake up. In panic I stabilized the dream by burrowing my hands (I somehow had a body again) into the ocean floor. I found many large marbles in the sand [of the ocean floor]. Then I tried to decode the numbers, but had difficulties to find the beginning of the math problems (felt a lot of time pressure because of the fear to wake up from the loud stimuli). Identified a 4 and a 5, moved my eyes 4 times to the left and 5 times to the left, but these [body signals] are probably not very clean. Then I woke up.

During this dream, REM sleep was obviously successfully detected, and stimuli were played including coded messages. The stimuli were incorporated directly into the dream, however, as the dreamer states, they were far too loud so that a successful sleep communication could not be conducted due to the fear of waking up. This is another hint for the necessity of an effective stimulus control from within the dream with the possibility to change the stimulus intensity, too. The dreamer was lucid, and detected the incorporated stimuli. However, if one compares the dream report and from the log, the dreamer decoded a "4" and a "5", whereas a "9" and a "0" have been sent into the dream world. The Morse codes for "4" and "9" and for "5" and "0" are very similar, the dreamer mixed up long and short tones (4: four short and one long tone, 9: four long and one short tone; 5: five short tones, 0: five long tones). Since the dreamer did not understand a complete math problem, he responded just the numbers he understood back.

However, the body signals given were also not correctly encoded according to Morse code (the "4" would have needed one additional eye movement to the right). Nevertheless, the wrongly coded body signals could be identified manually.

Thus, for a successful sleep communication, several important points were missing. First, the dream was not long enough for the dreamer to decode a complete math problem. Second, the few numbers which the dreamer did decode, were wrongly decoded. And third, the body signals were encoded wrongly, too.

As a result, it can be concluded from these partly successful sleep communications that an efficient training of the message coding scheme is important, and even if the subject knows the coding scheme when being awake, this does not mean that he can remember it easily while dreaming. Moreover, a stimulus control from within the dream is necessary.

NON-SELF-EXPERIMENTS

Aims

The main goal of the experiments with other subjects was to try to repeat the successful dream communication of the self-experiments under sleep laboratory conditions with PSG and other persons as subjects. Additionally, practical experiences and subjects' feedback for future sleep communication experiments were looked for, for example on benefits and disadvantages of the sleep laboratory at University of Osnabrück, on how to organize such a sleep experiment in general, on how to best conduct a PSG and on finding out more about inter-personal variability in sleep experiments.

Methods

These non-self-experiments took place in the sleep laboratory at the NeuroBioPsychology at the University of Osnabrück. There were five subject, all students at the age between 20 and 25. They had mixed lucid dreaming experience (see Table 3).

Subject	Total previous lucid dreams	Lucid dreams per month
1	2	0-1
2	15-20	1
3	70-80	3-4
4	100	3
5	20	4-5
average	42.9	2.5

Table 3: Lucid dreaming experience of the pilot study's subjects

Before the first night, the participants were informed about the details of the experiments (see Appendix C). All subjects provided written informed consent. There was no monetary compensation for the study.

The participants answered one questionnaire before the first night, one after each night and one after each awakening from a dream (which was filled out in an interview-fashion by the experimenter).

All subjects were trained before the first night in decoding the relevant Morse code signals (i.e., the numbers from 0 to 9, "P" for plus and "M" for minus), first in theory and then in practice with 1000 Hz sinus tone stimuli (the same stimuli as were used in the experiment during the nights). They were also trained in signaling answer messages using eye movements to the left and to the right. They were informed to give the signal "look five times to the left (and in between back to center)" for signaling that they have a lucid dream. This signal is different to the left-right-left-right signal normally used in lucid dream research but was chosen in order to make it easier to detect in the Zeo EEG.

All subjects were asked to stay two consecutive nights in the sleep laboratory. Subject S3 offered to stay one additional night in the sleep laboratory. During all nights, the subjects wore the Zeo headband.

Subjects S3, S4 and S5 were additionally recorded with a polysomnographic device, a NeuroScan (amplifier and software) system, during their second (and for S3 also the third) night. This system recorded 19 channel EEG, horizontal and vertical EOG and chin EMG. Impedance was kept below 5 kΩ. Data was sampled at 500 Hz.

For REM sleep detection the same method as in the self-experiment was used. The same stimuli as in the self-experiment were used (computer generated 1000 Hz sinus tone). Again, a stimulus was played if out of the last 300 seconds, 50 % or more were classified as REM.

As written above, the "big" main aim of the experiments was to conduct a successful sleep communication. This includes: (1) The person to sleep communicate with has to be sleeping and dreaming, and this has to be detected by a dream sleep detector or by a body signal detector, (2) playback of a stimulus containing a message, possibly encoded using a coding scheme (here: a random math problem), (3) incorporation of the stimulus into the dream, (4) lucidity of the dreamer, (5) correct detection of the incorporated stimulus by the dreamer, (6) correct decoding of the stimulus message if a coding scheme is used, (7) comprehension of the message transported by the incorporated stimulus by the dreamer, (8) heeding the incorporated message by the dreamer and thinking about a response, (9) sending the response back to the wake world by encoding it into a body signal, and (10) correct detection and decoding of the body signal by hand or machine (here: an eye movement signal).

In order to enhance the chances for such a complete successful sleep communication, several sub-aims and their corresponding methods were defined for each of the two nights: During the first night of the experiment, one sub-goal was to find out the stimulus intensity at which the subject wakes up from REM sleep. Thus, the stimulus intensity (=loudness) was started at low level and then increased until the subject woke up. The wake-up intensity level was then noted. This had the additional effect that REM sleep during the first night was reduced. In previous studies it was shown that this REM sleep deprivation has no harmful effects on healthy humans (Vogel, 1975), but to have the effect of a REM sleep rebound in the following night, i.e. the "stolen" REM sleep is caught up on in the following night (Dement et al., 1966) which is of course beneficial for the sleep communication since more REM time means more time for trying to sleep communicate. Another sub-method of the first night was to record dream contents of the subjects in order to look out for recurring contents which might help the subject to become lucid during the second night.

In the second night, stimuli were played below the waking threshold determined during the first night. Additionally, subjects were woken up approximately 5 hours after going to bed in order to apply two lucid dream inducing techniques: wake-back-to-bed (WBTB) and mnemonic-induced-lucid-dreaming (MILD). WBTB means that the subject is waken up, held awake for approximately 20 to 30 minutes, and then goes back to bed. During this time awake, the subject was asked to rehearse the decoding and answering of the Morse coded math problems, to intensively think about the previously recorded dreams and to imagine how he could have become lucid during the dreams, and to go back to sleep with the intention: "The next time I dream, I will remember to recognize, that I am dreaming!" (MILD).

During both nights, the recording was stopped when the subject declared to not being able to fall sleep anymore.

The experimenter (the author of this thesis) was awake during all the nights.

Results

Questionnaire results

All subjects were asked to fill out two types of questionnaires: a questionnaire filled out before the first night, and a second questionnaire filled out after every night.

The questionnaire filled out before the first night revealed that no subject knew any Morse code signals before the experiment, apart from the Morse code "SOS" which two subjects knew beforehand. Two subjects stated to make use of reality testing ("reality checks") in order to increase the probability of lucid dreaming, one subject claimed to have used this method but to have stopped using it, one subject does not use any lucid dreaming techniques at all and one subject uses the technique of falling back into a previously dreamed dream after waking up. On the question whether the subjects have regularly occurring dream contents, three subjects could name some, for example flying out of the bedroom window. This question aimed at finding dream contents that might help the subjects to realize that they are dreaming ("next time I fly through a bedroom window I realize that I am dreaming"), especially for the MILD and WBTB method used during the second night. However, none of the few reported regularly occurring dream contents were reported in any of the dream reports during the experiments and thus, could not help with increasing lucid dream probability.

The questionnaires filled out every morning after finishing the sleep experiment show that the overall sleep quality (measured using the German school grading system, from 1: very good to 6: insufficient) was quite poor in the first night (average of 4), however, became much better in the second and third night (average of 2). Subjects explained the poor first night sleep quality by the unfamiliar sleep experiment situation and the unfamiliar environment. Surprising is that the PSG recordings taking place during the second night, which were thought to disturb normal sleep behavior much more than the simple Zeo headband, were not reported as worsening the sleep quality. All subjects complained about the heat in the sleep lab, especially since there was no possibility to open a window. Some of the subjects complained about the sound of the ventilation system. All subjects stated that the tones of the experiment had negative impact on their sleep quality, which is not surprising since the subjects were woken up by the tones multiple times. Nevertheless, all subjects found the experiment interesting and exciting, and three of the five subjects even stated that they enjoyed the experiment and would like to participate in follow-up studies.

Conducting sleep communication

DREAM DETECTION AND STIMULUS PLAYBACK

Determining an exact success rate on how well dream sleep was detected by the Sleeator 2 is not possible from the data of this study since it is unknown how many dreams have been missed by the dream detector. A possible method for determining the dream detection success rate could be to wake up the subject multiple times throughout the night and then to analyze in how many cases a dream detector correctly detected dream sleep ("true positive"), in how many cases it detected dream sleep even though there was none ("false positive"), in how many cases it did not detect dream sleep even though there was some ("false negative") and in how many cases it correctly detected non-dream sleep ("true negative"). In this study, however, the focus was laid on trying to conduct a sleep communication, and not on a statistical analysis of the dream detection success rate. Nevertheless, and despite the fact that the false negative and false positive classifications are unknown, at least the positive classifications can be briefly analyzed. Out of the 42 awakenings of all subjects in all nights, 30 resulted in a dream report. Thus, the probability for sending signals into a dream instead of non-dream sleep when dream sleep is detected by the Sleeator 2 (using the combined Zeo and self-programmed classifier approach) is about 71 %.

Dream contents and Incorporations

The dream reports show a broad variety of dream contents, ranging from flying in a colorful hot-air balloon to juggling with "devil sticks", from "Asterix and Obelix" to the in-dream invention of a new drinking game called "AlphaBeta". However, there were also dream contents that were repeatedly reported among subjects: dreams about the sleep lab, the experiment and the experimenter, dreams about university and its professors, dreams about using Facebook, and dreams about getting rid of things, especially nerving sounds and tones. This touches the question of incorporations of the experiment tones. All subjects reported at least one dream in which the experiment tones were clearly directly or indirectly built in. One exemplary dream report of such incorporation is the following (translated from German into English):

"I was outside at the square between the AVZ [university building] and the Physics building. The sleep experiment took place there somehow. I was not lucid. I heard around 20 beeps during the dream, and I asked Kristoffer [the experimenter], who was also there, to please turn off the sounds, but he wouldn't. This annoyed me very much. Then I wrote a message to Tessa [a friend of the subject] via Facebook and asked her whether she could turn off the sounds. But that was not possible. Then I woke up. "

Other incorporations were for example a nerving beeping mobile phone which was thrown through the room in order to turn off the beep tones, an annoying beeping of university computers identical with the experiment's tones, a beeping blood donation machine and a beeping radar set on a ship.

There were 30 dream reports over all subjects, out of which 6 reported direct incorporations and 6 reported indirect incorporations. A direct incorporation was counted if the sinus tone was present during the dream but not connected to any dream contents and incorporated with the same sound as the real stimulus tone, an indirect incorporation was counted if it was clearly identifiable as the beeping stimulus sound and connected to dream content, e.g. the beeping mobile phone. Other cases which were not doubtlessly identifiable as incorporations, for example "there was music which was somehow similar to the tones", were not counted as incorporations. As a result, 12 out of 30 dreams (40 %) showed direct or indirect incorporation. Multiplying this with the probability of sending signals into a dream instead of non-dream sleep when dream sleep is detected (71 %), this gives a chance of 28% for generating a dream incorporation when REM sleep is detected, given this REM detection method and the used stimulus.

LUCIDITY AND BODY SIGNALING

Given the average number of 2.5 lucid dreams per month per subject, there is only an average chance of 8.3 % for a lucid dream per night for one subject (assuming lucid dreams are as probable in the experimental sleep laboratory environment as in daily life, which might very well not be the case). Thus, the probability for at least one lucid dream during the eleven nights of recording the subjects in the sleep laboratory was 1-(0.917^11) = 62 %.

Two subjects had lucid dreams in the sleep lab. Subject 1 had a very short lucid dream during his second night in the sleep lab, only one second long according to the dream report. Unfortunately, the stimulus generation was not started yet (still in the waiting phase). The subject lost lucidity and did not become lucid again when the stimulus was played later and got incorporated into the dream as a mobile phone sound.

Subject 5 had three lucid dreams during her second night in the sleep lab.

In her first lucid dream, which took place around 3:41 am, she reported to have been eating in her bed together with her sisters. The stimulus was directly incorporated into the dream. She was lucid, but reported difficulties to stay lucid. She also reported that she was aware of the incorporated stimuli and that she knew that the stimuli were encoded numbers, and tried to give the lucidity signal (looking five times to the left). However, the subject reported that she had difficulties with sending the lucidity signal due to distraction from the dream, and the PSG recording shows some possible eye signals, but these are not very clean and could possibly be normal dream eye movements, too.

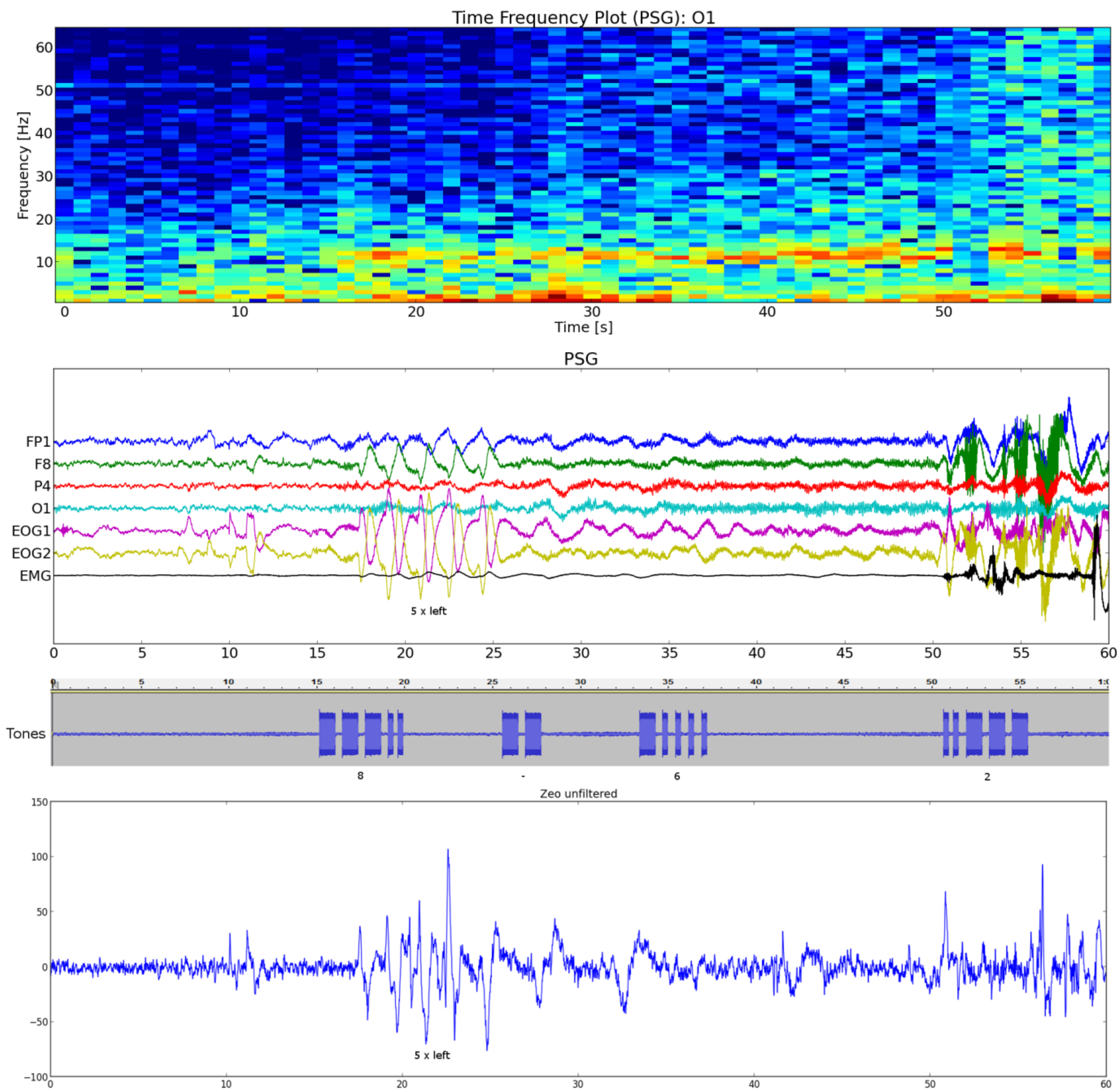

Figure 24: The lucidity signal of subject 5 during her second lucid dream can be clearly seen in the EOG data.

The second lucid dream of subject 5, which took place around 5:16 am, showed the best results regarding sleep communication. The dream started as a continuation of the previous dream with her sisters. Next, the subject reported that the scenery then changed and she walked around the

AVZ university building and took pictures of the nearby trees with her camera. She became lucid due to an inconsistency of the dream: the sun light came from both behind her and from the top of the trees, which she realized not to be possible in the real world. She could hear the stimuli being directly incorporated into the dream (however, in her dream report after awakening she could not remember exact numbers or operators), and gave the lucidity signal (see Figure 24). Recognizing how close she was to a successful sleep communication, she became extremely excited (she stated her heart to have been racing), which unfortunately woke her up before she could give further signals. The PSG data, the tones and the Zeo data are shown in Figure 24.

It can be seen in Figure 24 that the subject woke up around second 50, which can be nicely seen in the EMG signal (increased muscle tonus from second 50 on), probably due to the tones. Moreover, one can clearly see the lucidity signal at second 17 in both EOGs and (as an artifact) also in some EEG channels, consisting of five times looking to the left. The Zeo data show this signal as well, even though this signal is not as clean as the EOG's one. Furthermore, the excitement of the subject can also be found in the EEG data, represented by an increase of beta and gamma band EEG activity.

The third lucid dream of subject 5 took place around 8:16 am. Unfortunately, the subject was not able or did not want to give a dream report[9], but stated, that she was dreaming lucidly and that she could hear the incorporated stimuli. Moreover, she could name two stimuli (a zero and a minus) which she decoded during the dream. She did not give a lucidity signal because she "wanted to wait until a complete math task is finished" in order to answer without being distracted by eye movement signaling before. However, she woke up 15 seconds before the first complete math task was incorporated into the dream. Nevertheless, the two stimuli she could detect have indeed been sent into the dream, as can be seen in Figure 25 – the last three signals sent into the dream were minus, three and zero, out of which the subject remembered the minus and the zero. The first incorporated stimulus, in the illustration around second 10, directly led to signal changes in all channels of PSG. Moreover, the other stimuli lead to PSG signal change, too, especially in the frequency domains of 0-4 Hz (probably eye movements artifacts, maybe

[9] This was explicitly allowed to the subjects in case there were very private dreams.

due looking around from where the incorporated stimuli originate) and of 8-12 Hz (alpha waves). The latter frequencies have been shown to be associated with pre-lucid dreaming and bizarre content (Tyson et al., 1984), but have also been suggested to be facilitating the dreaming brain's connection with the wake world and to be enabling the incorporation of external stimuli (Cantero et al., 2000). This fits the data, as the alpha waves occurred every time when there was a stimulus played.

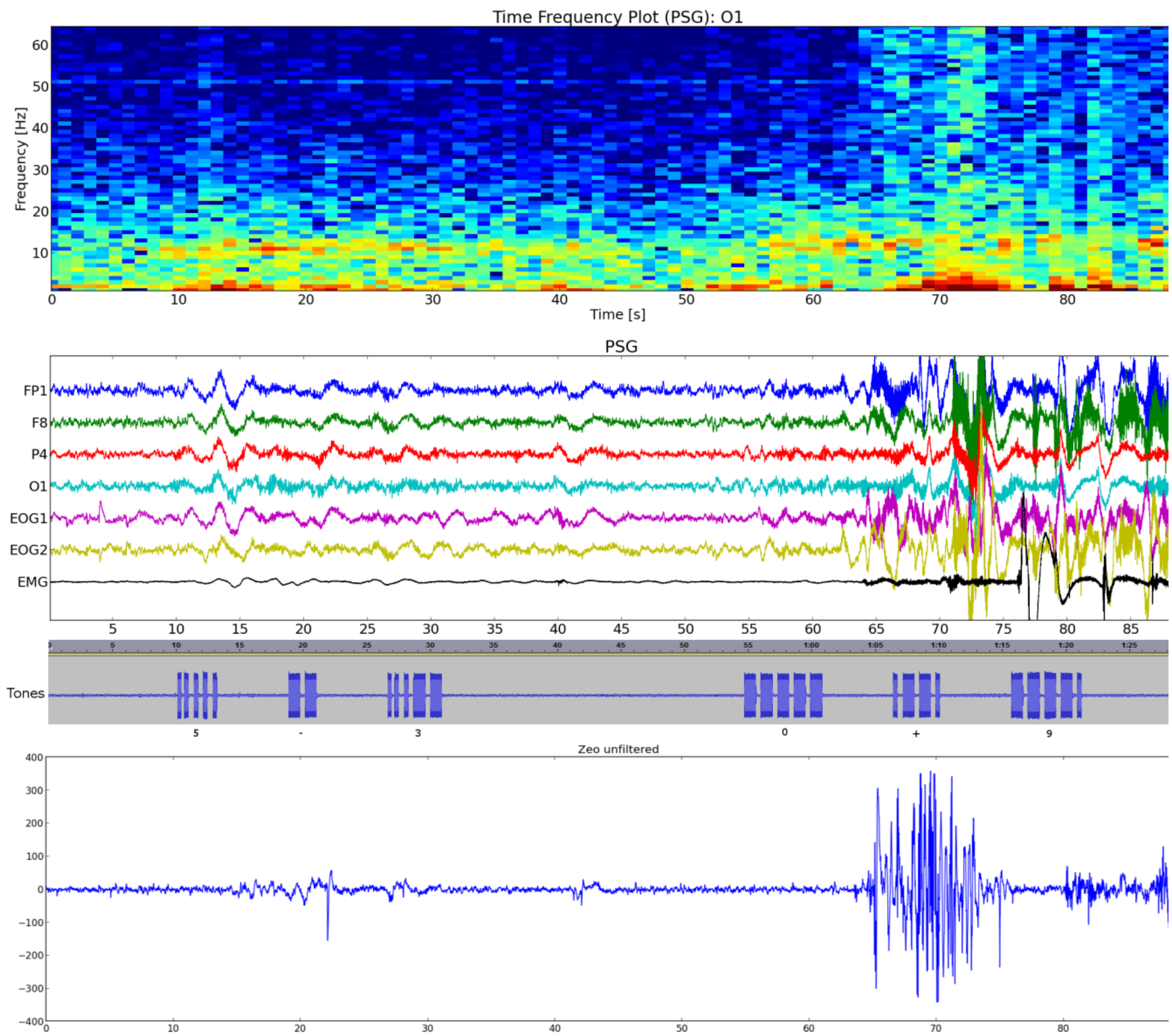

Figure 25: Correspondence between stimuli and EEG activity

SUMMARY OF THE EXPERIMENTAL PILOT STUDY

The experimental pilot study led to several results. Most importantly, it was shown that a successful sleep communication is possible using the Sleep Communication Framework and the Sleeator 2 together with the Zeo as its implementation. The successful sleep communication consisted of a math problem with random numbers and operators which was sent into the dream, solved inside the dream without awakening, and sent back to the wake world. The successful sleep communication was recorded by EEG and dream report. Additionally, further (partly successful) attempts during the self-experiments and during the non-self-experiments showed some very promising results, too, as for example a dream of subject 5 in which she correctly identified stimuli that had been incorporated into her dream, but unfortunately woke up before she could answer a complete math problem.

Since the resources (especially the time resources) have been limited in this master thesis project, only a pilot study with a relatively low number of participants (five from the non-self-experiments plus one from the self-experiments) and a low number of nights recorded (eleven plus two, not counting the early self-experiments during the development process of the Sleeator 2) could be conducted. Thus, an advanced statistical analysis, on how well the ten requirements for a successful sleep communication as given by the Theory of Sleep Communication can be fulfilled using the Sleep Communication Framework and the Sleeator 2 implementation, does not seem legitimate. However, these ten points shall at least informally be commented on, based on the experiences of this pilot study:

(1) The person to sleep communicate with has to be sleeping and dreaming, and this has to be detected by a dream sleep detector or by a body signal detector and (2) Playback of a stimulus containing a message, possibly encoded using a coding scheme (here: a random math problem): About 71 % of the awakenings of subjects of the non-self-experiments following stimulus presentation took place during dream sleep. This number, however, has to be treated with caution, as it strongly depends on the device and the REM detection algorithms used. As stated above, further studies focusing on this point are necessary. The stimulus generation (1000 Hz sinus tones) was performed automatically by the Sleeator 2, which led in some cases to the result

of too loud stimuli. From this experience, it can be concluded that a stimulus control (on, off, intensity) from within the dream is necessary. (3) Incorporation of the stimulus into the dream: All of the in total six subjects incorporated the stimulus into at least one dream, which shows that even this very simple stimulus of 1000 Hz sinus tones can be used for sleep communication. On average, incorporations could be found in 40 % of the reported dreams. (4) Lucidity of the dreamer: This point was the bottleneck of the experiments. Only two of the five subjects of the non-self-experiments were able to produce lucid dreams (one of which only had a one-second lucid dream); moreover, maintaining the lucid state without waking up long enough to fulfill the task was not possible to the independent subjects. Thus, there was only one lucid dream during the self-experiments long and stable enough to attempt a complete sleep communication, which succeeded. It could be found out, that if the sleeper has a lucid dream, it is also possible to actively look out for incorporations, as has been shown in this one lucid dream in which the dreamer looked for something that could beep, found it and then was able to sleep communicate. Increasing the chances to obtain and maintain lucidity thus seems to be a crucial point for future sleep communication. (5) correct detection of the incorporated stimulus by the dreamer: There were no subjects who have falsely identified something in their dream as an incorporated stimulus. Whenever the subjects reported an incorporation, there was a stimulus played before. However, this might also be due to the low number of subjects and nights. (6) correct decoding of the stimulus message if a coding scheme is used: there are mixed findings concerning this point. In the completely successful sleep communication, five of five incorporated signs have been decoded correctly, however, there were also some numbers wrongly decoded in the first nights of the experiment due to mixing up long and short Morse signals. An easier to decode message coding scheme or more training before sleep communicating might help overcome this problem. (7) comprehension of the message transported by the incorporated stimulus by the dreamer: If there was a message decoded, there was never a problem like: “4+4. What does this mean?” On the contrary, the two subjects having decoded incorporated numbers during their dreams stated to have known perfectly well what these messages were good for. (8) heeding the incorporated message by the dreamer and thinking about a response: In the dream report of the one completely successful sleep communication, no problem was stated with calculating the solution to 4+4. However, the message at hand was not very complex, further research on more complex messages is needed. (9) sending the response back to the wake world by encoding it into a body signal, and (10) correct detection and decoding of the body signal by hand or machine (here: an eye movement signal): Again, apart from the lucidity signal, which was successfully sent several times by both (partly) sleep communicating subjects, only a few answer numbers have been sent by encoding them into body signals. However, nearly all of these body signals could be decoded by hand, even using only the Zeo EEG and the eye movement artifacts within the signal.

Chapter 6: Summary and Discussion

There has been previous research on how to detect REM sleep, leading for example to the AASM Manual (Iber & American Academy of Sleep Medicine, 2007) on sleep stage classification. There has been previous research on dream-affecting stimuli, for answering the question: "What wake world stimuli become incorporated into dreams and to what extent?" (see chapter 2). There has been previous research on how to give signals from within a (lucid) dream to the wake world, up to the point at which sleeping persons signaled single Morse code signs to the wake world (e.g., LaBerge et al., 1981a).

There has been (few) previous research on combining these three components in order to let the sleeping person react to stimuli played during sleep. The "maximum" was a study which showed that subjects were able to discriminate between two single tones during sleep by reacting with a simple eye movement to the left (Strelen, 2006).

However, a scientific sleep communication theory combining the three components dream incorporations, lucidity and body signaling, and adding a coding scheme for exploring the possibilities of arbitrary message exchange with a sleeping person, in both directions from wake world into sleep world and from sleep world into wake world, was still missing, and was now developed first in this thesis. Furthermore, a Sleep Communication Framework describing the details of a technical implementation enabling sleep communication, with all its requirements concerning hardware and software and the interfaces between all the parts of this framework has been developed here, too. Next, in order to test this Sleep Communication Framework, a concrete implementation following the requirements of the Sleep Communication Framework was developed. This concrete implementation called "Sleeator 2", consisting of the Zeo as a main hardware device and thousands lines of Python code on the software side, offers an all-in-one solution for everything necessary for sleep communication, as well as additional components, as for example regarding data visualization or recording. Finally, a pilot study consisting of self-experiments and non-self-experiments was conducted, leading to one complete successful sleep communication, and several partly successful sleep communications.

Thus, the goal of demonstrating at least one successful sleep communication with arbitrary, content filled messages ("proof of concept") could be reached.

Even though there is strong evidence for sleep communication working given by the experimental results of this work, the results should still be validated using parallel PSG and independent rating of sleep stages in order to water-proof that the sleeper is really sleeping and not awake. Unfortunately, due to the low number of lucid dreams in the sleep laboratory and the restricted time resources of this master's thesis, it was not possible to completely repeat the successful sleep communication with a PSG. This remains open and should definitively be conducted in following studies.

However, it seems to be only a question of time until a sleep communication with PSG is successfully recorded since the concept worked in the self-experiment, and also the results of the non-self-experiments show promising results. Thus, it seems legitimate to conclude that sleep communication as described in this thesis is possible and that the Sleep Communication Framework implemented by the Sleeator 2 seems to be a good basis for this purpose.

Naturally, the resources of this master's thesis project were limited, and since this master thesis's topic is very complex, the time resources have set restrictions as to how far the development of the sleep communication and its testing in a sleep laboratory could be extended. As a result, the Sleeator 2 implementation of the Sleep Communication Framework created here is far away from being perfect. On the contrary, every single part of the implementation can be easily improved.

The REM detection could make use of better machine learning algorithms and better suited hardware.

The stimuli used for dream incorporations could be improved, which includes the kind of stimuli, and also the combination of multiple stimuli for an increase in communication speed.

The message coding scheme (here, the Morse code was used for both directions of communication) could be replaced by a faster and easier to learn/use scheme. One idea for this would be to use a stimulus-specific coding scheme which makes use of the properties of the stimulus. The same applies for the messaging from sleep world to wake world.

The transportation mode for messaging from sleep world to wake world could be improved, e.g. by using other modes than eye movements or combining different message transportation modes in order to increase the communication speed.

The automatic message decoding for communication from sleep world to wake world could make use of more advanced machine learning algorithms, maybe even be specialized on a specific transportation mode.

A better stimulus control from within a dream could improve the power and efficiency of sleep communication.

Moreover, the Sleeator 2 software could be improved by increasing its overall stability and fault tolerance, by increasing the performance, by further enhancing the visualization capabilities and the user's GUI experiences, by better structuring and documentation of the code, and by extending the interfacing capabilities to other hardware and modules using different software.

Additionally, the sleep communication in general can be brought forward by developing more reliable lucid dreaming inducing techniques. This is probably the most important point for improving the sleep communication concept. A key role for this lies probably in a better understanding of the neuro-causal mechanism underlying lucid dreams. Noreika et al. (2010) suggest to use transcranial magnetic stimulation (TMS), transcranial direct current stimulation (tDCS), and galvanic vestibular stimulation for investigating these causal relationships. Another idea for such an analysis could be to apply the new method for detecting causality in complex ecosystems by Sugihara et al. (2012) on lucid dreaming data. Moreover, if combining this with a suited lucid dreaming inducing technique, as for example the SSILD technique (see appendix A), or one of the techniques suggested by Noreika et al., it could become possible to determine which part of a technique has a causal relationship with inducing lucid dreaming. It could even become possible to determine why a given technique does not work for specific people and could give valuable hints (like bio feedback) for these people to see what they have to change for bringing this technique to success.

Another idea on how to induce lucid dreaming more reliably is the use of (legal) drugs. At the beginning of the 20th century, Freud already had the idea of modifying dreams in a neurochemical way (Freud, 1917). Applied to lucid dreaming, dreams can be altered by administration of neurochemicals to the subject, leading to more lucid dreams. This was for example shown in a study by LaBerge (2003) where an acetylcholine esterase inhibitor class drug (Donepezil) usually used for treating Alzheimer's disease seemed to have a strong effect on increasing lucid dream probability. Another study by Yuschak (2007) suggests that a combination of REM promoting substances and deep sleep suppressing substances (Galantamine, Sulbutiamine, Caffeine, and Desmopressin) leads to highly probable lucid dreams.

Lastly, an objective sleep communication quality measurement should be developed for comparing different approaches to sleep communication. This measurement should include a total quality index, a communication speed measure, and also objective sub-measures for the ten points necessary for successful sleep communication given by the Theory of Sleep Communication. It has to be possible to analyze for instance: "Applying light flashes instead of sinus tones increases the sleep communication speed by a factor of 1.35, increases the incorporation rate by a factor of 1.6 and thus leads to an overall sleep communication quality index improvement of 1.12."

However, even though there are numerous possibilities for improvement, this thesis produced a stable ground, a working setup, on which can be built and which can now be extended and further bettered. One of the most important benefits of the Sleep Communication Framework developed here is its modularity which allows partial improvements. The big frame is set and the improvement of a part as for example the eye movement detection can be done in a small project, and then be easily integrated into the big framework, leading to immediate positive effects on sleep communication.

Chapter 7: Future Prospects

If you can dream it, you can do it. (Walt Disney)

The reader might wonder: Why? What is this sleep communication good for? Admittedly, sending a simple random math problem into the dream of a sleeping person does not look like being of the utmost importance for manhood – honestly, at a first glance, it does not seem to be of any use at all.

But, if one sees this new technology of transmitting arbitrary messages from wake world to dream world and from dream world to wake world as a fundamental work being the basis of other future technologies, this point of view might change. Only a few of these possible future technologies shall be described here briefly.

ENTERTAINMENT

One use for sleep communication today already could be seen in its entertaining abilities. Since this technology is brand new, exploring its possibilities can be very enjoying, as the author of this thesis has experienced firsthand. It was never as amusing to solve a simple math problem as during these dream experiments.

But the entertaining prospects of sleep communication are by far more tremendous than this. A first idea could be to send simple words into the dream world, like "love, peace, and harmony" or "adventure, moon, aliens" in order to see in how far the dream content can be influenced by this.[10] Guided dreams could become possible with this, like reading a book or watching a movie, but experiencing the story within a dream. Taking this idea a step further and making use of the two-directional possibilities of sleep communication, an interactive way of guided dreaming like in today's computer games could be possible – but with the difference of "really" being a Prince

[10] It is not meant by this to subconsciously play some words, but to use sleep communication as described in this thesis for this – i.e. the sleeping person consciously receives the message.

of Persia or a Jedi Knight instead of just controlling them on a computer screen, experiencing the story told with one's "own" body and feelings.

LEARNING OF NEW KNOWLEDGE DURING SLEEP

Without sleep communication, it is obviously not possible to transport new knowledge into the dreams of a sleeping person. Of course, knowledge and skills learned during the day are rehearsed during sleep and sleep has been shown by numerous studies to be very important for this, but learning information never heard before during sleep is not possible up to today. With sleep communication, this can become possible for the first time in history. Just imagine, you are a student, the night before the exam you go to sleep, and during sleep you just learn the necessary knowledge to succeed in the exam! A very simple experiment for this can be easily conducted even now already: Instead of sending random math tasks into the dream world, new information can be sent to the dreamer, for example the most important events of the 10th century. After awakening the dreamer would be tested on the new knowledge learned during sleep. This could further be extended to a more interactive way of learning, since sleep communication works in both directions, making teaching with a teacher-student concept possible. With further advancement in sleep communication, it might even be possible one day e.g. to dream of being in the ancient Rome, having Julius Caesar as a private tutor for learning Latin (or, being taught the French language by Asterix & Obelix).

NEW PSYCHOTHERAPEUTIC INSTRUMENT

Instead of using sleep communication for entertaining or learning purposes, this technology could also be used in a clinical way to treat psychiatric disorders. This might make possible a new way to treat nightmares live in a coached manner, to help overcome anxiety or other disorders.

ARTISTIC USAGE

Musicians, artists, writers or other creative people could benefit from using sleep communication. For example, artists could place themselves in a very special dream scenery (e.g., sitting on Mount Everest) and create wake world art by messaging their painting movements via an advanced brain-computer interface to the wake world, where it controls a prosthesis with a real paintbrush. Another exemplary future use illustration could be a musician, being a fish with human hands within his dream, expressing his fish feelings and emotions in a "fish song", which is transferred to the wake world using sleep communication with a very fine-tuned hand muscle EMG as body signal, which again controls a musical instrument.

The exemplary future prospects seem quite spectacular, and many more of these future prospects can be thought of. However, sleep communication has to be further improved in order to make these prospects possible. Especially, there is more research needed on which stimuli, body signals, and message coding schemes can improve sleep communication the best. Furthermore, more reliable methods have to be developed to induce lucid dreams.

You can design and create, and build the most wonderful place in the world. But it takes people to make the dream a reality. (Walt Disney)

APPENDICES

Appendix A: Senses Initiated Lucid Dream (SSILD) Official Tutorial

The SSILD technique, developed by a blogger with the pseudonym Cosmic Iron, retrieved on 04.09.2013 from http://cosmiciron.blogspot.de/2013/01/senses-initiated-lucid-dream-ssild_16.html

Background

SSILD is a modern lucid dreaming technique. It is easy to learn, highly effective, and produces consistent results over period. I developed this technique in 2011 in order to teach lucid dreaming to fellow dreamers on a Chinese forum. The first written version of the technique was published under the title "太玄功", which literally translates to "A Very Mysterious Technique". This is rather fitting because at the time no one had the faintest idea why it worked. Despite this lack of theory, the feedback on the technique was overwhelmingly positive. Within just a few months we gathered many hundreds of success stories!

Building on this initial success, we continued to refine the technique, and it essentially became a collaborated effort among hundreds of people. The tutorial went through a few revisions, and with each version we saw improvements in ease of use and effectiveness. A year later I wrote the first English version of the tutorial and published it on a few lucid dream online forums. This time I chose the name "Senses Initiated Lucid Dream", partly to conform to the unofficial but widely accepted naming convention of LD techniques, and partly due to increased knowledge and understanding gained during the past year.

While people on these forums appear more slow to embrace a brand new technique, the result was nonetheless quite promising. Between DreamViews and LD4All, there are more than a hundred success stories recorded in 9 months, within only two threads.

Today, SSILD has become one of the most popular LD induction techniques on the Chinese forum, which has grown to host more than 80,000 members. The numbers of success stories are too numerous to count. Another exciting aspect is SSILD's long-term sustainability. Whereas many techniques appear to become less effective over period as the users' initial enthusiasm wane, SSILD delivers consistent performance, turning novices to experts, and experts to masters. For example, more than a dozen members on my tiny personal forum are able to induce LDs on a daily basis. One of them even logged nearly 500 LDs/OBEs in full detail within less than a year, a remarkable achievement by all means.

Design Philosophy

SSILD is designed from the ground up to be simple, "idiot-proof" even. It does not utilize advanced techniques such as relaxation and visualization, and stays away from delicate, non-measurable mental exercises. It despises the notion that lucid dreaming is more "art" than "technique". It does not require you to be gifted or creative, in fact, there is little room for improvisation. Just follow the simple steps outlined here and you should be all set. SSILD is made so concise that if you mix in other stuff you may actually end up creating negative impact on its performance.

The "Cycle"

The core component of SSILD is called a "Cycle". Each cycle consists three steps:

Focus on Sight: Close your eyes and pay attention to the darkness behind your closed eyelids. Don't strain your eye muscles though. Your eyeballs should be resting, totally relaxed. If you don't see anything that's only normal. Do not attempt to spot visuals by moving your eyes around.

Focus on Hearing: Further relax your eyes and shift your attention to your ears. If the room is quiet enough you might be able to hear some noise inside your head or the sound of your heartbeat. However, if you can't hear anything it is okay to listen to external sounds too.

Focus on Somesthetic Senses (Touch): Direct your attention to your body. Feel it and see if you spot any unusual sensations such as tingling, heaviness, lightness, spinning sensations, and so on. If nothing like these can be felt, you can also try to feel the weight of the blanket, your heartbeat, temperature of the air, etc.

The repeated stimulation on the senses enables SSILD to condition our mind and body into a subtle state that is optimized for lucid dream to occur naturally. We should keep this in mind so we don't make the common mistake of "trying too hard" during the cycles. Beginners usually want to see things, hear things, and feel things. When nothing unusual happens they become discouraged or even desperate. Avoid this mistake at all cost! One should not expect to experience anything phenomenal during the Cycle. In fact, it is better to expect NOTHING at all will happen.

The Steps

1. Go to bed early, preferably before 11pm. Set your alarm to wake up after 4 or 5 hours.
2. Get out of bed and stay awake for 5-10 minutes. I suggest you visit the bathroom, rinse your mouth, and walk around or stretch a little bit. Try not to become too awake though.
3. Return to bed and lie down in a comfortable position, preferably different from the one you usually use. This is to prevent you from falling into sleep prematurely. However, if you are the type of person who requires extra effort to fall asleep, you may want to use the usual position instead.
4. Perform the "Cycle" quickly, repeat 4-6 times. This serves as a warm-up exercise so each step should be very short, a few seconds should be sufficient.
5. Perform the "Cycle" slowly, repeat 3-4 times. This step is the most important one. You should take extra time during each step. Thanks to step 4, at this point you should have become sufficiently relaxed and you will find focusing on the senses become much easier. For example, your eyes will feel more relaxed, and you may get visuals such as lights, colors, or movements. You might also notice

that the external sounds seem to be fading into the background. Do not get excited though. You should observe quietly and after a while move on to other senses. As far as timing goes we are flexible, but in general each step should take no fewer than 30 seconds.

During the slow cycles, you may become distracted by a lot of random thoughts. This is a good indication that you are close to falling asleep. Do not try to suppress these thoughts -- they are your friends. Imagine they are gentle waves and let them carry you and wash you away from the shore of reality. You will occasionally become alert and realize you have lost track of your exercise. No worry, just start from the beginning of a cycle and you should be fine.

6. Return to the most comfortable position and allow yourself fall into sleep as quickly as possible. Do not think too much and do not worry if it will work. The quicker you can fall asleep the more likely it will work. Have faith!

WHAT HAPPENS NEXT

One key characteristic of SSILD is that it is neither a WILD nor DILD technique. It is a hybrid. As such, it is important to become familiar with all the possible scenarios so you will maximize your chances.

1. Hypnagogia: when we enter a dream consciously, we often encounter various unusual hypnagogic sensations. These include the sensation of falling, floating, seeing lights and images, hearing sharp noises, and many more. In fact, sometimes you may encounter sensations so strange that they are beyond words. When we encounter these sensations, chances are we are already in a dream, or getting really close. SSILD is known to cause hypnagogia during the Cycles (although this effect should NOT be sought after). It's also not uncommon for you to wake up suddenly while being bombarded by intense hypnagogic sensations. When this happens you should not become excited. Be a passive observer and wait for the sensations to amplify. You could also nudge them a little bit mentally, but do not overdo it. As soon as the sensations become clearly identifiable you should be able to perform a successful reality check[11] and get up. Typically the dream will start from your bedroom because subconsciously that's where you expect you will be. You can also stay in bed longer and use visualization to create a dream scene manually. In any event, it is important for you to stay calm when encountering hypnagogia. Do not speak to yourselves or analyze it mentally as doing so can cause the sensations to fade and eventually wake you up.

2. False Awakening: SSILD is known to cause a lot of FAs. Not any FA, but some super-realistic ones! A typical scenario goes like this -- you finished doing SSILD and fell asleep. Then suddenly you wake up. No lucid dreams, perhaps not even a normal dream! Feeling disappointed you get out of the bed... then you wake up again! It was all but a dream! SSILD's ability to frequently create this

[11] A reality check is a simple test to detect whether one is dreaming or awake. There are hundreds of different reality checks. Example: Close your nose with your fingers. Breathe out. In a dream, breathing out is often possible, since the real body can breath out, too. In wake world, breathing through a closed nose is of course impossible.

type of FAs have been well-documented by now. Therefore, you should definitely develop the habit of performing a reality check upon each awakening after doing SSILD, no matter how convinced you are about your not being in a dream. Another possible scenario is that you slip into sleep during a SSILD cycle, and an FA immediately takes over. When this happens you may suddenly feel awake and it seems you are about to suffer insomnia. Some users complained that SSILD was causing them to lose sleep, only later found out they had been doing SSILD cycles in their dreams! Once you learn to catch these FAs your chance of success will be greatly improved.

3. DILD: When you fall asleep from SSILD, you enter your dreams with heightened awareness. As a result, lucid dreams occur. This is called Dream Initiated Lucid Dream (DILD). With heightened awareness, you may be able to spot oddities in dreams and in turn become lucid. It is also very common for spontaneous lucid dreams to occur -- you suddenly become lucid for no apparent reason.

4. Real Awakening: You wake up again after doing SSILD. You do a reality check and this time it is real. Do not despair. You still have chances. Try to stay still, and immediately relax your head, allowing the back of it to sink into the pillow. Then you need to perform a few extra medium-paced SSILD cycles. At this stage it is quite possible for you to encounter strong hypnagogia sensations. If not, just finish the cycles and go to sleep. You will have a much higher chance to succeed this time.

FAQ

Q: Can I do SSILD when I go to sleep?

A: Yes you can, but it won't work. When you go to bed you typically start with a lot of NREM sleeps which are not ideal for lucid dream to occur. The level of acetylcholine (an important neurotransmitter which is a major driving force for lucid dreams) is also at lower level. Trying to lucid dream with any technique at this stage is a waste of time, even though this is the favorite mistake virtually every beginners make.

Q: I'm used to go to bed late or have to get up early, can I still use SSILD?

A: I suggest you do SSILD only when you have sufficient time. Even though it does not take up a lot of time to perform, you WILL be losing some sleeps. As such, for people who never get enough sleep, your best bet is to do SSILD at leisure.

Q: Can I combine other breathing, meditation, relaxation techniques during or prior to doing SSILD?

A: No. As mentioned earlier, SSILD is all about "conditioning". You condition your mind and body to the most optimal state for lucid dream to occur. This state, however, is very delicate. Mixing in other techniques will likely interfere with this state and cause negative impact on SSLID's performance. You're free to create your own routines once you master the technique, but for beginners I expect you to adhere to the instructions in this manual.

Q: I get this itch... how am I supposed to stay still?

A: You are not supposed to stay still! If you have an itch just scratch it. If you want to roll you roll. With SSILD you need to stay as comfortable as possible! Just do an extra cycle to compensate and you will be fine. This is in fact a major advantage over virtually all other methods.
Q: My eyes strain/hurt when focusing on visions...
A: Remember, you should NOT expect to see anything, so relax already! Do not strain your eye muscles. Your eyeballs should be resting, if not staying still. Performing a few quick cycles will also help you relax.
Q: I can't feel anything when doing the cycles...
A: We cannot stress this more -- it is OKAY to not feel anything, and it is WRONG if you actively pursue it and expect things to happen during the cycles. With the cycles you are setting a timer for the bomb to go off. You don't expect a bomb to go off WHILE you are setting the timer do you? Sure, it does go off occasionally...
Q: I got insomnia after doing SSILD...
A: Actually, performing SSILD correctly is likely to cure your insomnia. There is a remarkable resemblance between SSILD and Betty Erickson's self-hypnosis routine! Now back to the question. We need to first identify if we are taking about "real insomnia" or "false insomnia". Remember, SSILD likes to create these super realistic false awakenings. It is very possible for you to enter an FA while still performing the SSILD cycles. In this case you will be trying to fall asleep while you are already sleeping! Next time you find yourself unable to fall asleep during a cycle, you should definitely perform a reality check, no matter how convinced you are! For people who indeed suffers loss of sleep due to SSILD, I suggest you tweak your routines in two areas: 1. Reduce the amount of sleep before waking up for SSILD. 2. Reduce the time you spend on staying awake prior to the exercise.

International Morse Code

1. A dash is equal to three dots.
2. The space between parts of the same letter is equal to one dot.
3. The space between two letters is equal to three dots.
4. The space between two words is equal to seven dots.

A	• —	U	• • —
B	— • • •	V	• • • —
C	— • — •	W	• — —
D	— • •	X	— • • —
E	•	Y	— • — —
F	• • — •	Z	— — • •
G	— — •		
H	• • • •		
I	• •		
J	• — — —		
K	— • —	1	• — — — —
L	• — • •	2	• • — — —
M	— —	3	• • • — —
N	— •	4	• • • • —
O	— — —	5	• • • • •
P	• — — •	6	— • • • •
Q	— — • —	7	— — • • •
R	• — •	8	— — — • •
S	• • •	9	— — — — •
T	—	0	— — — — —

Figure 26: Retrieved on 25th Sep 2013 from http://www.learnmorsecode.info

Appendix C: Instructions and Questionnaires for Study Subjects (in German)

Lieber Versuchsteilnehmer!

Vielen Dank für deine Bereitschaft, Proband bei den Versuchen zu meiner Masterarbeit zu sein!
Im Folgenden wirst du **Details** zu den dir bevorstehenden Nächten lesen können.

Wie du weißt, geht es in meiner Masterarbeit darum, **mit schlafenden/träumenden Menschen zu kommunizieren**, d.h. Nachrichten aus der Realität in die Traumwelt zu schicken, und Nachrichten aus der Traumwelt in die Realität.

Nacht 1:
In der ersten Nacht bestimmen wir deine **Weckschwelle**, d.h. die Lautstärke eines akustischen Signals, bei der du aus dem REM-Schlaf aufwachst. Um die Weckschwelle zu bestimmen, werden dir in deinem REM-Schlaf Pieptöne vorgespielt, in ansteigender Lautstärke, bis du aufwachst. **Sobald du wach bist, sagst du Bescheid**, und ich notiere die Lautstärke. Außerdem frage ich dich nach deinem **Trauminhalt**, den du mir knapp mitteilst. Du kannst Dinge weglassen oder „die Aussage verweigern“, wenn der Trauminhalt geheim bleiben soll. Dies wird die **ganze Nacht** hindurch wiederholt. **Nebeneffekt** dabei ist, dass du in dieser Nacht am **REM-Schlaf gehindert** wirst. Leicht- und Tiefschlaf sind „erlaubt“, werden also nicht gestört. Studien haben gezeigt, dass fehlender REM-Schlaf in folgenden Nächten nachgeholt wird, d.h. wenn wir versuchen, im Traum zu kommunizieren, hast du hoffentlich schön viel REM-Schlaf.

Ziele von Nacht 1 sind,
- deine Weckschwelle für REM-Schlaf zu bestimmen
- REM-Schlaf zu unterdrücken
- dich an die Schlaflaborumgebung zu gewöhnen
- Trauminhalte zu erfassen, die möglicherweise beim Klarwerden in der folgenden Nacht helfen können.

Nacht 2:
Die zweite Nacht besteht aus **zwei Teilen**.
Im ersten Teil der Nacht werden dir während deines REM-Schlafs **Pieptöne unterhalb deiner Weckschwelle** vorgespielt, die codierte Nachrichten enthalten. Was für Nachrichten das sind, steht weiter unten. Vielleicht hast du hier bereits einen Klartraum (Verhalten bei einem Klartraum s.u.).
Falls nicht, wirst du nach etwa 5 Stunden Schlaf geweckt, und wir wenden die sog. **WBTB** (Wake-Back-To-Bed-Methode („Aufwachen-(und)-Zurück-ins-Bett“)) in Kombination mit **MILD (**Mnemonic Induced Lucid Dream ("Gedächtnis-induzierter Klartraum")) an, **um die Klartraumwahrscheinlichkeit zu erhöhen**. Das geht so (ich helfe natürlich bei jedem dieser Schritte):
- nach etwa 5 Std. wirst du geweckt
- bleibst etwa 20-30 Minuten wach, währenddessen
- übst du nochmal das Entschlüsseln und Beantworten der Nachrichten
- denkst intensiv über deine bisherigen Träume nach und stellst dir vor, wie du zu einem beliebigen Zeitpunkt luzide geworden wärest
- nimmst dir fest vor, dich im Traum daran zu erinnern, dass du träumst

- gehst wieder schlafen mit der Intention: „**Das nächste Mal wenn ich träume, will ich daran denken, zu erkennen dass ich träume.**“

Ziele von Nacht 2 sind
- einen Klartraum zu induzieren
- zu versuchen, Nachrichten im Traum zu erkennen und zu beantworten.

Nachrichtencodierung:
Du wirst **leichte Matheaufgaben** im Schlaf lösen, z.B. 3+5.
Die Matheaufgaben werden in Form von Pieptönen in den Traum transportiert. Es gibt **kurze und lange Pieptöne**. Zwischen einzelnen Zeichen befindet sich jeweils eine kurze Pause. Dabei bedeuten (in Anlehnung an das Morsealphabet):

Zahlen:
Eins (1): Kurz Lang Lang Lang Lang .----
2: ..---
3: ...--
4: ….-
5: …..

6: -....
7: --...
8: ---..
9: ----.
0: -----

Zeichen:
P: .--. (plus) Kurz Lang Lang Kurz
M: -- (minus) Lang Lang

Beispiel:
...-- .--. ….. 3 + 5
--... -- ..--- 7 - 2

(vergleiche auch die Hörproben (*.mp3-Dateien)
Das **Beantworten von Matheaufgaben** ist ähnlich, nur dass du dafür deine Augen benutzt. Statt Kurzer Ton, blickst du von der Mitte deines Blickfeldes aus schnell nach weit Links und wieder in die Mitte zurück; statt Langer Ton nach Rechts.

Beispiel: Möchtest du die Antwort „8“ senden, also ---..
Mitte **Rechts** Mitte Mitte **Rechts** Mitte Mitte **Rechts** Mitte Mitte **Links** Mitte Mitte **Links** Mitte

Wichtig ist, immer wieder in die Mitte zurückzukehren und den Blick dort kurz zu fixieren, um ein gut lesbares Signal zu erzeugen.

Verhalten bei einem Klartraum:
1. Zeichen geben. Die Augen 5 mal von der Mitte des Blickfeldes schnell nach weit links bewegen. (ML ML ML ML ML)
2. Traum stabilisieren, z.B. indem du deine Traumhände anguckst und benutzt.
3. Nachrichten im Traum suchen. Diese können versteckt sein (Bierkastengeklirre, Würfelbecher, …) oder direkt „im Original“ im Traum auftauchen.
3. Ggf. Lautstärke des Signals anpassen: Lauter (ML ML ML), leiser (MR MR MR).
4. Nachrichten entschlüsseln und beantworten.

Wir üben das ganze natürlich noch in Echt. Hört sich komplizierter an, als es ist!
Gute Träume
Kristoffer

Einverständniserklärung

Bezeichnung des Laborexperiments: Kommunikation mit Schlafenden
Laborexperiment geleitet von: Kristoffer Appel

Beschreibung:
Das Experiment untersucht, ob und inwieweit eine Kommunikation mit Schlafenden möglich ist. Es werden ungefähr 10-20 Studenten, Männer und Frauen über 18 Jahren, angeworben, die an diesem Experiment in mehreren Sitzungen teilnehmen werden. Eine Sitzung wird eine Nacht, d.h. ca 9 Stunden dauern.
In dem Experiment werden den Teilnehmern während des REM-Schlafes (einem Schlafstadium mit hoher Traumwahrscheinlichkeit, in Gegensatz zu z.B. Tiefschlaf) Töne vorgespielt, die (so die Absicht) teilweise in den Traum eingearbeitet werden. Der Teilnehmer erreicht entweder durch die Töne oder auf andere, selbstbestimmte Weise Klarheit, d.h. erkennt, dass er träumt, und und versucht, die in den Traum eingearbeiteten Töne zu finden und die darin enthaltenen Nachrichten (leichte Matheaufgaben) zu entschlüsseln. Der Teilnehmer "antwortet" dann aus dem Traumzustand heraus in die Wachwelt mithilfe von Augenbewegungen.
Am Anfang und am Ende der Sitzung werden die Probanden gebeten, einen Fragebogen auszufüllen. Ferner werden dem Teilnehmer nach Erwachen aus Träumen (auch nachts) Fragen zum Trauminhalt gestellt. Der Teilnehmer kann die Beantwortung der Fragen ohne Konsequenzen befürchten zu müssen verweigern. Es werden weder Ton- noch Filmaufnahmen der Sitzungen gemacht, allerdings werden EEG (Hirnströme), EMG (Muskelanspannung am Kinn) und EOG (Augenbewegungen) aufgezeichnet und ausgewertet.

Risiken und Vorteile:
Die Teilnahme an den Laborexperimenten ist mit keinen dem Versuchsleiter bekannten Risiken oder direkten Vorteilen verbunden.

Kosten und Entgelt:
Es werden keine weiteren Kosten für die Teilnehmer entstehen außer ihrer Zeit. Es wird keine Aufwandsentschädigung gezahlt.

Vertraulichkeit:
Alle Informationen, die sich auf teilnehmende Personen beziehen, werden in digitaler Form abgespeichert. Sie werden nur den am Experiment mitwirkenden wissenschaftlichen Mitarbeitern zugänglich sein. Die Ergebnisse können auch anderen Forscher zur Verfügung gestellt werden, aber keine Informationen, durch die die Teilnehmer identifiziert werden können.

Das Experiment abbrechen:
Die Teilnehmer sind nicht verpflichtet, an dem Experiment teilzunehmen, und können es jederzeit verlassen. Ihre Entscheidung, an dem Experiment teilzunehmen, wird keine Auswirkungen auf ihren akademischen Status oder andere Vor- oder Nachteile für sie haben. Ein Teilnehmer kann von dem Experiment ausgeschlossen werden, wenn er während der Sitzung nicht die Anweisungen des Experimentators befolgt. Der Experimentator kann auch entscheiden, die Sitzung wegen Software-Fehler oder aus einem anderen Grund abzubrechen.

Freiwilliges Einverständnis:
Die oben aufgeführten Informationen wurden mir erklärt und meine Fragen dazu wurden beantwortet. Ich weiß, dass zukünftige Fragen ebenso vom Experimentator beantwortet werden. Mit meiner Unterschrift bestätige ich, dass ich an dem beschriebenen Laborexperiment teilnehmen möchte.

____
(Name und Unterschrift des Teilnehmers)
Osnabrück, ________________________________

Bestätigung des Experimentators:
Ich bestätige, dass das Ziel und die Durchführung des geplanten Laborexperiments, sowie die potentiellen Vorteile und Risiken, die damit verbunden sind, den Teilnehmern erklärt worden sind. Ihre Fragen dazu wurden ebenfalls beantwortet.

____
(Name und Unterschrift des Experimentators)
Osnabrück, ________________________________

Fragebogen vor der ersten Nacht

Name ____

Alter ___________

Geschlecht **[ ] männlich** **[ ] weiblich**

Gewöhnliche Zu-Bett-Geh-Zeit ______

Gewöhnliche Aufsteh-Zeit ______

Gewöhnliche Dauer bis zum Einschlafen _______

Kanntest du vor diesem Experiment bereits Codes aus dem Morsealphabet? Wenn ja, welche?

____

Gibt es in deinen Träumen wiederkehrende Inhalte? Wenn ja, welche und wie regelmäßig treten diese auf?

____

____

____

Wie viele luzide Träume hast du ca. im Monat? _________

Wie viele luzide Träume hattest du bisher in etwa insgesamt? _________

Verwendest du bestimmte Techniken, um luzide Träume hervorzurufen? Wenn ja, welche?

____

____

Datum _______________

Ich erkläre mich damit einverstanden, dass meine Daten im Rahmen dieser Studie anonymisiert ausgewertet werden.

Unterschrift _______________________

Fragebogen nach erfolgter Weckung

Name ____

Datum _______________

Uhrzeit _______________

Geschätzte Traumdauer: ____________

Wovon hast du geträumt? (notfalls Rückseite nutzen)

____

Warst du luzide, d.h. hast im Traum gemerkt, dass du träumst?

____

____

Konntest du während des Traumes im Traum die Töne hören oder eingearbeitet wiederfinden? Wenn nein, kannst du im Nachhinein etwas im Trauminhalt entdecken, das mit den Tönen zusammenhängen könnte?

____

____

Konntest du während des Traumes Nachrichten entschlüsseln? Wenn ja, welche? Wenn nein, was hat dich daran gehindert?

____

____

Konntest du während des Traumes mit Augenbewegungen Signale geben? Wenn ja, welche? (Luzidität, Antworten, Lautstärke) Wenn nein, was hat dich daran gehindert?

____

____

Fragebogen morgens nach dem Aufstehen

Name ____

Benote im Schulnotensystem:

Wie gut hast du geschlafen? ____

Gab es besondere Vorkommnisse während der Nacht?

____

____

____

Was hat dich in deinem Schlaf gestört?

____

____

____

Hast du Verbesserungsvorschläge für dieses Experiment?

____

____

Gibt es Sonstiges, das du gerne mitteilen möchtest?

____

____

____

Datum _____________

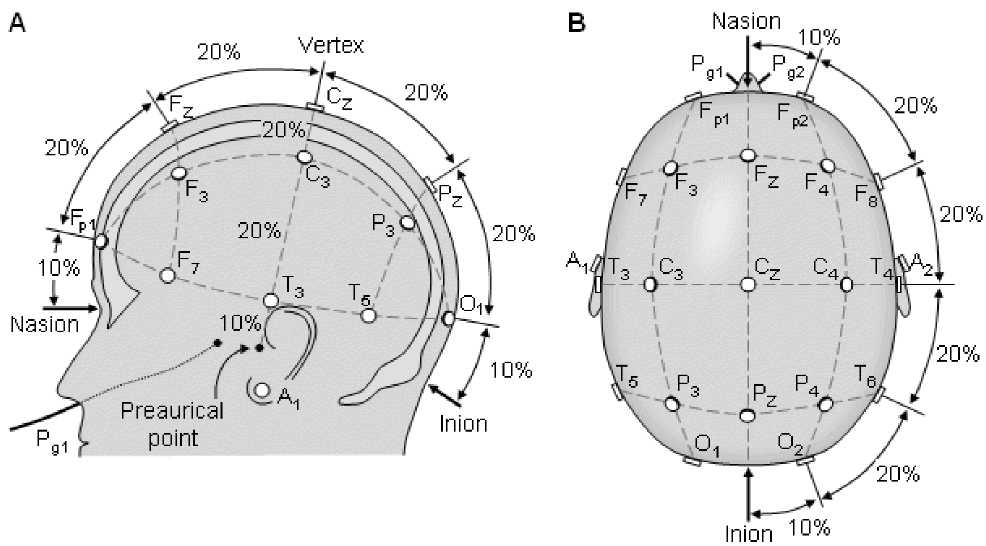

Figure 27: Overview of the electrode positions in the 10-20-EEG system, which was used for the PSG recordings (image source: Malmivuo and Plonsey, 1995)

Appendix E: DVD

(attached)

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