Empirical investigations of lucid dream induction methods and individual differences in lucid dream frequency

Achilleas Pavlou

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Department of Psychology

University of Essex

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FORWARD

Lucid dreaming (LD) is defined as the awareness of being in a dream with increased cognitive abilities including the availability of autobiographic memory sources and the ability to actively control the dream. The overall aim of this thesis is to understand individual differences in lucid dream frequency (LDF), how they affect LD induction rates in LD techniques practise and to work towards developing LD induction techniques that can induce LDs reliably and easily. This work will firstly explore the theoretical background of sleep, sleep stages and polysomnography. Thereafter, the theoretical background of dreams, LD and LD induction techniques will be explored. Afterwards, three experimental study chapters will investigate individual differences in LDF, the effectiveness of a combination of a popular set of cognitive induction techniques (Reality Testing + Wake-Back-To-Bed + Mnemonic Induced Lucid Dreaming) and the efficacy of a novel external stimulation technique and framework. This external stimulation technique created in this work sends out personalised computerised text-to-speech audio cues and uses predictive machine learning algorithm to present stimuli as close to, but safely below one's individual auditory awakening threshold (AAT), to enhance stimulus incorporation and LD induction rates.

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.

Colchester, 25/04/21

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LIST OF ABBREVIATIONS

AASM: American Association of Sleep Medicine

AAT: Auditory Awakening Threshold

AIM-Model: Activation-Input-Modulation Model

CPAP: Continuous Positive Airway Pressure

CST: Costly Signalling Theory

DRA: Dream Recall Amount

DRC: Dream Recall Completeness

DRF: Dream Recall Frequency

ECG: Electrocardiography

EDA: Electrodermal activity

EEG: Electroencephalography

EMG: Electromyography

EOG: Electrooculography

ERP: Event-related potential

FFMQ: Five Facets of Mindfulness Questionnaire

GSR: Galvanic Skin Response

IAM: Individually Adjusted Method

IAS: Individualised Auditory Stimulation

iLOC: internal Locus of Control

IRASA: Irregular Resampling Auto-Spectral Analysis

LDF: Lucid Dream Frequency

MA: Micro-Arousal

MILD: Mnemonic Induced Lucid Dreaming

ML: Machine Learning

MMN: Mismatch Negativity

mPFC: Medial-Prefrontal Cortex

N1/NREM 1: Stage 1 non rapid eye movement sleep

N2/NREM 2: Stage 2 non rapid eye movement sleep

N3/NREM 3: Stage 3 non rapid eye movement sleep

NFC: Need for Cognition

NREM: Non rapid eye movement sleep

PGO: Ponto-Geniculo-Occipital

PHT: Psychological Healing Theories

PPG: Photoplesmography

PPT/LDT: Pedunculopontine and Laterodorsal Tegmental Nuclei

PRMQ: Prospective and Retrospective Memory Questionnaire

PSG: Polysomnography

PTSD: Post-Traumatic Stress Disorder

RAT: Random Activation Theory

RC: Reality check

REM: Rapid Eye Movement

REMs: Rapid-Eye movements

RLS: Restless Legs Syndrome

RMS: Root Mean Square

RT: Reality testing

SAT: Stimulus Awakening Threshold

SFT: Sentinel Function Theory

SSILD: Senses Initiated Lucid Dreaming

SW: Slow Wave

SWA: Slow Wave Activity

SWS: Slow Wave Sleep

tACS: Transcranial Alternate Current Stimulator

tDCS: Transcranial Direct Current Stimulator

TPJ: Temporo-Parietal Junction

tRNS: Transcranial Random Noise Stimulator

WBTB: Wake-Back-To-Bed

WILD: Wake Induced Lucid Dreams

YASA: Yet Another Spindle Algorithm

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OVERVIEW

« [...] πολλάκις γὰρ καθεύδοντος λέγει τι ἐν τῇ ψυχῇ ὅτι ἐνύπνιον τὸ φαινόμενον. ἐὰν δὲ λανθάνῃ ὅτι καθεύδει¸ οὐδὲν ἀντιφήσει τῇ φαντασίᾳ. »

(…or often, when one is asleep, there is something in consciousness which declares that what then presents itself is but a dream. If, however, he is not aware of being asleep, there is nothing which will contradict the testimony of the bare presentation.)

Aristotle (350 BC), writings on lucid dreaming in *On Dreams*

This overview will briefly define lucid dreaming (LD), the individual characteristics associated with lucid dreaming frequency, previous induction techniques and the potential applications of lucid dreaming. An outline description of each chapter will be provided, and the aims of the thesis will be discussed in brief at the end of the overview.

The brain has the innate ability to act as an internal virtual reality generator, generating complex visuals scenes, scenarios, and imaginary characters, in the form of dreams (Hobson, Hong & Friston, 2014). LD is a metacognitive state within a dream, that ranges from passive knowledge that what is experienced is merely a dream and not waking life, to having to having active, volitional control of the dream (Barrett, 1992).

LD is a rare occurring phenomenon (that can be trained or induced to occur more frequently – see below), with Saunders et al's. (2016) recent quality effect meta-analysis of LD prevalence and frequency studies, estimating that the proportion of individuals who have experienced at least one LD in their lifetime is 55% with 23% report experiencing lucid dreams once a month or more. Various researchers have looked at personality characteristics that seem to be positively correlated with LD occurrence, such as Openness To Experiences of the Big Five

personality dimensions (e.g Hess, Schredl and Goritz, 2016), Mindfulness (Stumbrys & Erlacher, 2017), internal Locus Of Control, Need For Cognition and Creativity (e.g Blagrove & Hartnell, 2000) and Dream Recall Frequency (e.g Watson, 2001). Lucid dream frequency (LDF) correlates will be discussed in more detail in chapter 2 and in chapter 3 a variety of potential correlates will be investigated.

The scientific study of the LD state has been validated through the use of psychophysiological measures including electroencephalography (EEG), functional magnetic resonance imaging (fMRI), electromyography (EMG), electrooculography (EOG), electrocardiography (ECG) and pressure transducers (Hearne, 1978; LaBerge, 1980; LaBerge et al, 1981; LaBerge and Dement, 1982a; LaBerge and Dement, 1982b; LaBerge et al, 1983; Fenwick et al., 1984; LaBerge, 1990; Erlacher & Schredl, 2008; Voss, Holzmann, Tuin & Hobson, 2009, Dresler et al., 2012; Erlacher et al., 2013). Key brain areas implicated with lucid dreaming are the frontotemporal regions of the brain: areas highly implicated with cognition/meta-cognition (Voss et al., 2009; Dresler et al., 2012). Specifically, the reactivation of these areas which are normally deactivated in normal dreams coupled with a rise in gamma band activity (when compared to normal dreaming) is thought to explain the improvement in metacognitive capabilities experienced whilst in an LD (Voss et al., 2009; Dresler et al., 2012).

LD has been demonstrated to have a variety of applications. Lucid dreaming has been shown be beneficial in psychotherapy in alleviating symptoms of PTSD and people who experience recurrent nightmares (Gavie, 2010; Holzinger, Klösch & Saletu 2015; Zadra & Pihl, 1997; Spoormaker & Van Den Bout, 2006). LD research has also demonstrated that lucid dreams can help improve motor skills and has been applied in sport performance enhancement (Schädlich, Erlacher & Schredl, 2016; Erlacher, 2005; Erlacher & Chapin, 2010; LaBerge & Rheingold,

1990; Tholey, 1991). Additionally, the LD state has been used to conduct cognitive research, for example to investigate sensory attenuation, self-other distinction and predictive processing frameworks (e.g., Windt, Harkness & Lenggenhager, 2015).

In order to access these benefits and applications of LD, various LD induction methods have been explored in the literature, such as cognitive techniques, external stimulation and drug applications (Stumbrys et al., 2012). However, up to now all techniques leave a lot to be desired in terms of achieving a high success rate. In this thesis, cognitive and external stimulation techniques will be given special focus: a combination of cognitive techniques will be investigated in study chapter 4, whilst in Chapter 5 a novel external stimulation technique which utilizes machine learning algorithms will be explored.

Chapter 1 will introduce the theoretical basics of the sleep-onset stage and of sleep per se, with its two alternating stages, NREM and REM sleep. Where appropriate, when introducing main aspects of sleep, they will be related to concepts of LD research. The final point of note for this chapter will be the methodology used in traditional polysomnographic recordings as well as recent advancement in polysomnographic techniques, focusing on sleep tracking devices and computer algorithms for automatic sleep scoring and signal processing techniques. The computer algorithms and wearable device that are used in Chapter 5 will be described in Chapter 1.

In Chapter 2 the various theories behind dreams and the neurobiological studies conducted on dreams are described. Thereafter, the theoretical background of lucid dreaming is laid out, including studies on the prevalence and frequency of lucid dreams, psychophysiological measures used for the scientific study of lucid dreams and methodologies utilized to trigger a

lucid dream state. Special focus is given to studies that have employed various methods of stimuli presentation during NREM and REM sleep for various purposes (such as biasing dream content and/or increasing learning and triggering LD). The chapter will end by outlining the various benefits and applications of conducting research in the area of LD.

In Chapter 3 surveys are reported that not only ascertain whether past findings on LD frequency correlates are replicated but also investigate possible novel correlates of lucid dream frequency (LDF).Among a variety of potential correlates, Chapter 3 investigates cognitive and metacognitive correlates relating to waking and dream memory as well as how different aspects of mindfulness relate to LDF. In addition, LD induction technique practices in online LD communities are investigated.

In Chapter 4, the combination of 3 cognitive LD induction techniques: reality check (RC), Wake-Back-To-Bed (WBTB) and Mnemonic Induced Lucid Dreaming (MILD), are investigated in an online two-week study. Cognitive techniques refer to cognitive tasks that practitioners are asked to perform during the day or whilst falling asleep which have been shown to help trigger a LD to happen (Stumbrys et al., 2012). This combination of cognitive techniques was chosen as it has been shown to achieve the highest induction rates when compared to other cognitive LD induction techniques, or when these techniques are used in isolation (Aspy et al., 2017; Aspy, 2020). Whilst the study in Chapter 4 borrows from the protocol used in Aspy et al., (2017), the study takes a deeper dive into the potential correlates that make someone successful at inducing LDs using this combination of techniques. In addition, as opposed to Aspy et al's. (2017) pen and paper study, is fully digitised. This digitisation not only includes the online delivery of the questionnaire but also delivers the

MILD technique in an audio guided form that is listened to whilst participants are instructed to fall asleep whilst practising it.

In Chapter 5 a novel LD induction framework is explored. It utilises external stimulation (an auditory stimuli) during dream sleep and aims to adjust stimulus properties to the individual to enhance LD induction rates. External stimulation techniques are techniques where external stimuli, such as light flashes or audio, are presented during dream sleep with the aim of incorporating them into the dream content to alert the dreamer that they are dreaming (Stumbrys et al., 2012). In this sleep lab study, the data and the stimuli are delivered through a small sleep wearable device. The stimulus is a speech audio file which will call out participants' first names and informs them that they are dreaming (e.g., "Achilleas, you are dreaming"). The chapter makes a special case for the use of participant first names, as it has been found previously in non-LD related studies that presentation of first names activates areas implicated to LD (e.g., Portas et al., 2000; Portas, 2005; Voss et al., 2009; Dresler et al., 2012).

Finally, Chapter 6 serves as a conclusionary chapter to the PhD thesis, that sums up the most important insights of the research that was conducted in chapters 3-5.

Thesis aims

The thesis aims were as follows:

1) To enhance our understanding of individual differences in LDF and subsequently look into the interplay of individual differences and lucid dream induction techniques. The purpose of this aim is to aid in the development of tailor-made approaches to induce lucid dreaming in the future. Firstly, to achieve this aim, Chapter 3 investigates a multitude of potential LDF correlates through survey-based questionnaires.

Subsequently, in Chapter 4, the significant LDF correlates are investigated further in a longitudinal study to observe how LDF correlates affect LD induction when practising a combination of cognitive LD induction techniques.

2) To develop a novel theoretical and technical framework for inducing LDs through external stimulation. This framework postulates that in order to enhance LD induction rates through external stimulation, research must be conducted into the requisites for successful stimulus incorporation into the dream content. Successful incorporation will translate into in-dream cues to signal the dreamer that they are dreaming. Moreover, when it comes to the mode through which stimuli become incorporated into the dream content, the framework runs on the supposition that in order to increase stimulus incorporation rates (and therefore LD induction rates), "a one-size fits all" approach is unlikely to be highly successful. Thus, stimuli must be tailored to the individual because the attenuation of external stimuli during sleep varies from person to person. The stimulus adjustment approach taken in this framework was the adjustment of external stimuli properties so that they are presented as close to, but safely below individual stimulus awakening thresholds (SATs). The foundation for this framework is laid out in the theoretical Chapters 1-2, whilst Chapter 5 aimed to provide the building blocks of this framework by experimentally testing aspects of it in a novel LD induction technique called the Individualised Auditory Stimulation (IAS). The study in chapter 5 specifically took a data-driven approach and included analysing behavioural data, looking into sleep macrostructure (sleep stage duration and latencies, etc) but more importantly, looking into a variety of sleep EEG microstructure (spindle, slow wave, K-complex, sleep stage band-power characteristics, etc). When it comes to LD research, the latter has never been done before in this depth. A key aim of the study in Chapter 5 was to develop behavioural

and EEG markers that can be attained through early parts of the night and analysed to provide stimulation that is tailored to the individual.

3) To research the efficacy of automatizing certain aspects of cognitive and external stimulation techniques, such as including audio guided versions of cognitive/external stimulation techniques and using guided written materials that could be implemented in a dedicated sleep wearable LD device and app. Chapter 4 explores this through the use of an audio-guided version of the cognitive technique MILD and electronically written materials (including instructions, questionnaires, automated email reminders, etc). In Chapter 5, a research-grade sleep wearable was coded so that the whole experiment was ran automatically without requiring any input from the experimenter. This included, but not limited to, auditory instructions, audio-guided training, automatic detection of REM sleep and automatic delivery and adjustment of stimulation. Post-data collection, the behavioural and EEG data acquired prior to stimulation were then fed to a ML algorithm pipeline whose aim was to predict whether an individual would have a low or a high awakening threshold. Thus, the aim of Chapter 5 was a proof-of-concept into the supposition that stimulus awakening thresholds can be predicted prior to any stimulation and that future studies and/or wearable technologies could use this LD induction protocol and the ML algorithm to automatically adjust stimulus properties to the individual.

CHAPTER 1

Theoretical Background of Sleep, Sleep Stages and Polysomnography

“ἡ δ’ Ὕπνον μετὰ χερσί, κασίγνητον Θανάτοιο, Νὺξ ὀλοή, νεφέλῃ κεκαλυμμένη ἠεροειδεῖ. ἔνθα δὲ Νυκτὸς παῖδες ἐρεμνῆς οἰκί’ ἔχουσιν, Ὕπνος καὶ Θάνατος, δεινοὶ θεοί· οὐδέ ποτ’ αὐτοὺς Ἠέλιος φαέθων ἐπιδέρκεται ἀκτίνεσσιν οὐρανὸν εἰσανιὼν οὐδ’ οὐρανόθεν καταβαίνων. τῶν ἕτερος μὲν γῆν τε καὶ εὐρέα νῶτα θαλάσσης ἥσυχος ἀνστρέφεται καὶ μείλιχος ἀνθρώποισι, τοῦ δὲ σιδηρέη μὲν κραδίη, χάλκεον δέ οἱ ἦτορ νηλεὲς ἐν στήθεσσιν· ἔχει δ’ ὃν πρῶτα λάβῃσιν ἀνθρώπων· ἐχθρὸς δὲ καὶ ἀθανάτοισι θεοῖσιν.”

"Nyx, (Night) carries Hypnos (Sleep) in her arms, and he is Thanatos' (Death's) brother . . . And there [near the house of Nyx in the underworld] the children of gloomy Nyx have their houses. These are Hypnos and Thanatos, dread divinities. Never upon them does Helios, the shining sun, cast the light of his eye-beams, neither when he goes up the sky nor comes down from it. One of these, across the earth and the wide sea-ridges, goes his way quietly back and forth, and is kind to mortals, but the heart of the other one is iron, and brazen feelings without pity are inside his chest."
From Hesiod, Theogony 758 ff (trans. Evelyn-White) (Greek epic C8th or C7th B.C.)

1.1 Human sleep

Sleep is a complex, highly organized state associated with reversible changes in consciousness, neuronal network firing properties, cerebral blood flow, gene expression profiles, brain chemistry and autonomic nervous system activity (Binder, Hirokawa, Windhorst, 2009). An average healthy person will sleep around eight hours every night, equating to spending roughly 1/3 of their lives sleeping.

Many theories exist about the core function of sleep but no single theory can explain it entirely, as many processes, from the molecular to the cognitive level, occur during sleep (Krone & Vyazovskiy, 2019). Krone & Vyazovskiy (2019) outline these processes as follows: macromolecule biosynthesis and intracellular repair (Cirelli et al., 2004; Mackiewicz et al.,

2007; Varshavsky, 2012; Vyazovskiy & Harris, 2013); brain detoxification via intra/extracellular metabolite clearance, which occurs through biochemical clearance of brain metabolites (Reimund, 1994; Inoue et al., 1995) and through the flushing of waste from the brain's extracellular space (Xie et al., 2013); energy conservation (Berger & Phillips, 1995) and energy replenishment (Bennington & Heller, 1995; Porkka-Heiskanen et al., 1997); memory consolidation (Feld & Born, 2017); and brain plasticity (Tononi & Cirelli, 2003; Tononi & Cirelli, 2014).

While there exist many theories about the function of sleep, one thing can be said with certainty: Sleep is a necessary biological need for the health and wellbeing of mammals (Campbell & Tobler, 1984; Zimmerman et al., 2008). This necessity for sleep is often demonstrated through sleep deprivation studies in humans and other species. In regard to the effects of sleep deprivation on the mind, sleep deprivation affects frontal brain areas resulting in the exhibition of slower EEG waves, shortened attention span, higher anxiety, impaired memory and irritable mood (Brown et al., 2012). Sleep deprivation has deleterious bodily effects, with lack of sleep causing immune function suppression (Besedovsky et al., 2012; Toda, Williams, Gulledge & Sehgal, 2019), increased risk of obesity and cardiovascular disease (Chaput & Dutil, 2016; Cappuccio, Cooper, D'Elia, Strazzullo & Miller, 2011) and decreased DNA repair gene expression, which in turn, leads to greater accumulating DNA damage (Cheung, Yuen, Wong & Choi, 2019; Zada, Bronshtein, Lerer-Goldshtein, Garini & Appelbaum, 2019). Sleep has been found to be one of the highest predictors of life span (Cappuccio, D'Elia, Strazzullo & Miller, 2010), with a recent large cohort study (N = 3759, over 20 years) by Spears, Montgomery-Downs, Steinman, Duggan & Turiano (2019) showcasing sleep as the indirect link between the so-called 'Big 5 personality traits' (Costa & McCrae, 1992) and mortality.

Sleep and sleep physiology is affected by a myriad of different conditions and disorders and therefore sleep physiological activity serves/could serve as a biomarker for diagnosing and providing predictors of therapy response and relapse in conditions such as depression (Murck et al., 2003; Steiger & Kimura, 2010; Pillai, Kalmbach & Ciesla, 2011; Steiger, Pawlowski & Kimura, 2015; Pawlowski et al., 2017) anxiety (Shanahan, Copeland, Angold, Bondy & Costello, 2014; Cox & Olatunji, 2016), ADHD (Konofal, Lecendreux & Corese, 2010; Merikanto et al., 2019), PTSD (Glaubman, Hananyah, Mikulincer, Porat, Wasserman & Birger, 1990; Kobayashi, Boarts & Delahanty, 2007), Autism (Mazurek & Sohl, 2016) and Alzheimer's disease (Mander, Winer, Jagust & Walker, 2016; Kam et al., 2019), to name a few.

According to the *American Academy of Sleep Medicine* (AASM) manual (Berry et al*.,* 2016), the leading and most frequently used sleep scoring manual (see more about the AASM in Polysomnography subheading), sleep consists of cycles of two uniquely characterised sleep types: the stage of rapid eye movement (REM) sleep and the three stages (N1, N2 and N3 or SWS) of non-rapid eye movement (NREM) sleep. Each sleep cycle consists of NREM and REM stages and together they usually last about 90-100 minutes, after which the cycle is repeated. Thus, in the typical eight-hour sleep of a healthy individual there are about five sleep cycles. The duration of REM sleep increases steadily throughout the night after each successive cycle of NREM and REM sleep (Brown et al., 2012). Dreams are most typically associated with REM sleep (although they can also occur during other stages, see Siclari et al., 2017). Thus, out of those eight hours spent sleeping, a normal healthy person is spending an estimated minimum of 1.5 hours each day in a dream state (Hobson, 2009), equating to spending a total of 6% of one's life dreaming.

1.2 Sleep Onset Stage

The transition from wakefulness to sleep is characterized by a multitude of gradual physiological and behavioural changes. De Gennaro, Ferrara & Bertini (2001) outline the physiological sleep onset changes as follows: Arousal is decreased (e.g., Davis et al., 1937; Dement and Kleitman, 1957a); the thalamus is largely deactivated (Maquet, 2000); saccades and endogenous blinking disappears (e.g., Santamaria & Chiappa, 1987); slow eye-movements appear (De Gennaro et al., 2000); muscle atonia increases (Hauri & Good, 1975); Galvanic Skin Response variability increases (GSR; Hori, 1982); body temperature drops (Van Den Heuvel et al., 1998); heart variability decreases (Burges et al., 1999) and intracerebral hemodynamics vary (Spielman et al., 2000). Gradual phenomenological/behavioural changes occurring during the wake-sleep transition phase are outlined in Goupil & Bekinschtein (2012). These include an increase in hypnagogic imagery hallucinations (see more about this phenomenon and its importance in lucid dream induction in Chapter 2); a gradual decrease in responsiveness to external stimuli until response cessation (Ogilvie et al., 1991; Casagrande et al., 1995;1997); a decrease in thought control (Yang, 2010) possibly due to the decrease in orbito-frontal cortex activity (Maquet, 1997; Hofle et al., 1997; Kaufmann et al., 2006); a loss of reality orientation (Foulkes and Vogel, 1965; Yang et al., 2010) and distortions in time perception (Gibson et al., 1982; Ogilvie 2001; Wackermann et al., 2002).

Hori, Hayashi & Morikawa's (1994) nine transitional electroencephalographic (EEG) stages (the so-called Hori stages) describe in detail the transitional changes from wakefulness to NREM 1 up to the beginning of NREM 2. They divide wakefulness into two stages, NREM 1 into seven stages and classify the beginning of NREM 2 as the final Hori stage. Hori stages are an improvement to the traditional clinical methodology of scoring sleep in thirty second epochs (see Polysomnography subheading), as the authors investigated electrophysiological and

behavioural changes occurring during the wake-sleep continuum, using five seconds epochs and wider scalp coverage (Goupil & Bekinschtein, 2012). The Hori sleep scoring system is currently one of the most complete descriptions of EEG changes from wake to NREM 2 sleep. Its stages are identified as follows:

- "Stage 1. *Alpha wave train*: Epoch composed of a train of alpha activity with minimum amplitude of 20 μV.
- Stage 2. *Alpha wave intermittent (A)*: Epoch composed of a train of more than 50% of alpha activity with a minimum of 20 μV.
- Stage 3. *Alpha wave intermittent (B)*: Epoch contained less than 50% alpha activity with a minimum amplitude of 20 μV.
- Stage 4. *EEG flattening*: Epoch composed of suppressed waves less than 20 μV
- Stage 5. *Ripples*: Epoch composed of low-voltage theta wave (20-50 μV) burst suppression.
- Stage 6. *Vertex sharp wave solitary*: epoch contained one well-defined vertex sharp wave.
- Stage 7. *Vertex sharp wave train or bursts*: Epoch contained at least one well-defined vertex sharp wave and one incomplete spindle (duration <0.5s, amplitude 10-20 μV).
- Stage 8. *Vertex sharp waves and incomplete spindles*: Epoch contained at least one well-defined vertex sharp wave and one incomplete spindle (duration <0.5s, amplitude 10-20 μV).
- Stage 9. *Spindles*: Epoch contained at least one well-defined spindle at least 0.5s in duration and 20 μV in amplitude." (Hori et al., 1994)

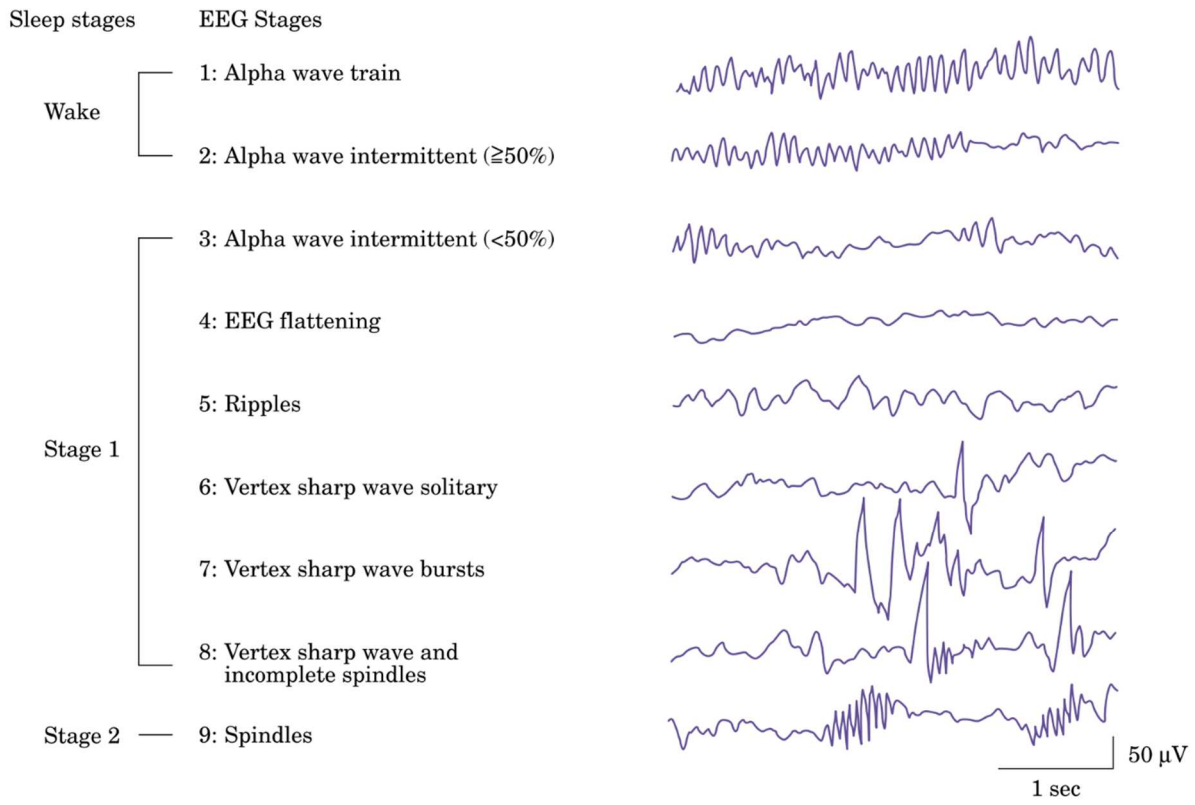

Figure 1.1. The nine Hori stages of EEG changes occurring from wake to stage 1 (NREM 1) and finishing at the beginning of stage 2 (NREM 2). Taken from Ogilvie (2001).

It is important to note some limitations of the Hori system, such that its stages are not transitioned uniformly and are absent in some sleep phenotypes, in some disorders/diseases or due to medications that affect alpha activity (Ogilvie, 2001). In addition, while five-second epochs offer more precision that the traditional thirty-second epoch scoring, it remains an artificial cut-off point that in some cases may lead to frequency bias (Ogilvie, 2001). Using the Hori system, or similar systems of analysis to understand the minute changes occurring in the wake-sleep continuum is extremely time consuming and impractical in most cases but it may be important in some circumstances (e.g. for lucid dreaming research). For example, lucid dream induction techniques, which utilize external stimuli (such as light flashes, tactile or auditory stimulation) to cue the dreamer that they are dreaming, could benefit from such a system. Specifically analysing smaller sized epochs could help select key moments during a REM epoch wherein participants are more receptive to external stimuli.

1.3 NREM Sleep

NREM sleep stage is divided into three distinct sub-stages, starting with NREM1 and then moving through NREM2 and NREM3 with each NREM sub-stage having its own electroencephalographic (EEG) and functional characteristics (Nir & Tononi, 2010). NREM sleep, unlike REM sleep, was traditionally not associated with dreaming. However, later studies have demonstrated that awakening participants during NREM can produce reports of dreaming at much higher instances than what was originally thought (Stickgold et al., 2001), although the phenomenology of NREM dream reports differ from REM (Martin et al., 2020); NREM dreams do not have the vivid visual hallucination component of REM dreaming and contain more thought mentation that is fragmentary and centred more on current daily concerns (Martin et al., 2020). Recent studies by Siclari et al. (2017) and Siclari, Bernardi, Cataldi & Tononi (2018) have identified posterior cortical activity with successful recall of dreams in NREM and REM. Specifically, Siclari et al (2017) were able to predict with high accuracy in real-time whether an awakening from NREM or REM sleep would produce a dream report (more detailed discussion on NREM dreams can be found in Chapter 2). While most lucid dreaming is thought to arise from REM sleep, some evidence exists from a two-case report, which demonstrates that NREM lucid dreaming might be possible (Stumbrys & Erlacher, 2012).

1.3.1 Non-REM 1 (NREM/N1) sleep

The N1 sleep stage is the stage of sleep that we usually initially enter once we fall asleep and is the lightest form of sleep and from which people can be easily awoken. It is characterised by decreased muscle activity, sudden muscle twitches, hypnic jerks, sometimes hypnagogic hallucinations and slow eye-movements. In regard to the EEG characteristics of N1 sleep, brain

oscillations start slowing down to a predominant activity of 8-13 Hz (alpha waves) and 4-8 Hz (theta waves).

1.3.2 Non-REM 2 (NREM2/N2) sleep

NREM2 sleep occupies 45-55% of adult sleep time and is characterised by further decreased muscular activity, a transition to predominantly theta wave activity with occasional K-complexes (large amplitude waves) and sleep spindles (figure 1.2).

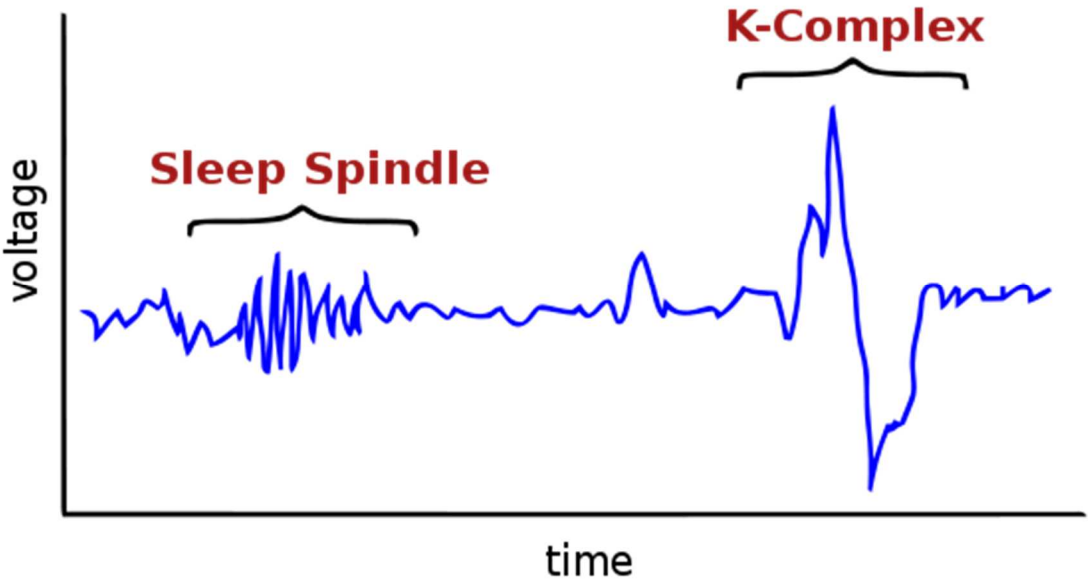

Figure 1.2. The sleep spindle and K-Complex sleep micro-events that usually occur together in NREM 2 sleep.

Sleep spindle activity consists of short bursts (0.5s - 2.5s maximum) of 11-16 Hz activity and is considered to be a defining characteristic of N2 sleep. Sleep spindles are generated by a combination of the intrinsic properties and connectivity patterns of corticothalamic neurons (Gennaro & Ferrara, 2003). While most prominent during N2, sleep spindles can appear in N3 sleep, but usually much less often, both when detected/scored visually (Guazzelli et al, 1986; Himanen, Virkkala, Huhtala & Hasan, 2002; De Gennaro, Ferrara & Bertini, 2000) and when

scored by automatic spindle algorithms (Dijk, Hayes & Czeisler, 1993; Zeitlhofer, Gruber & Saletu, 1997; Silvesrstein & Levy, 1976; Azumi & Shirakawa, 1982). Two types of spindles are thought to exist: 11.0-12.75 Hz spindles originating from frontal areas that are often termed as “slow” spindles and 12.5-14.5 Hz “fast” spindles originating from centroparietal areas (De Gennaro & Ferrara, 2003).

Multiple research studies support the notion that sleep spindles play a key role in memory consolidation (Rasch & Born, 2013) and cognitive abilities (Ujma, 2018). Memory consolidated in sleep is thought to occur through a process of covert reactivation of new memories that integrates them into long-term memory (Antony, Schönauer, Staresina & Cairney, 2019). Developmentally, in accordance with the development of thalamocortical networks in childhood and adolescence (Fair et al., 2010), sleep spindle characteristics change (Goldstone et al., 2019): peak sigma frequency increases across childhood and adolescence (Shinomiya et al., 1999, Tarokh & Carskadon, 2010; Cambell & Feinberg 2016); spindle duration and amplitude increase across early childhood (McClain et al., 2016); and older adolescents have greater spindle density than younger adolescents (Bodizs et al., 2014). The decrease in NREM 3 activity throughout adolescence is thought to be the reason behind spindle density and peak frequency changes (Goldstone et al., 2019), as NREM 3 activity has been linked with spindle activity (Uchida, Atsumi & Kojima, 1994, Ueda et al., 2001).

Sleep spindles are also associated with intellectual ability in the following ways (Ujma, 2018): Spindle amount/density and/or amplitude is positively correlated with increased learning abilities, particularly in tasks which require procedural memory (Fogel & Smith, 2006; Laventure et al, 2016; Morin et al., 2008; Nishida & Walker, 2007) and higher reasoning skills (Nader & Smith, 2001; 2003; Bódizs et al., 2005; 2008; Schabus et al., 2006; Fogel et al., 2007;

Ujma et al., 2014;2015; Fang et al., 2017). While some previous small-scale studies have found an association between spindle density and frequency with cognitive ability, a recent study by Pesonen, Ujma, Halonen, Räikkönen & Kuula (2019) found no such association; only fast spindle amplitude was associated with cognitive ability. These authors' largest to-date, adolescent birth cohort study on sleep spindles and cognitive abilities (N = 176), investigated the association between IQ measures (short version of Wechsler Adult Intelligence Scale III (WAIS-III; Wechsler, 1997) and sleep spindles, using two different automatic sleep spindle detector algorithms ('Ferrarelli method' - Ferrarelli et al., 2010; 'Individually adjusted method' (IAM) - Bódizs, Körmendi, Rigó, & Lázár, 2009) and compared IQ measures with the following sleep spindle characteristics: fast/slow sleep spindles density, duration and amplitude. The Ujma (2018) meta-analysis on the association between sleep spindles and cognitive ability, which included the then unpublished data of Pesonen et al. (2019) study, supported the Pesonen et al. (2019) findings claiming that "spindle amplitude alone is unambiguously associated with cognitive ability". While Ujma (2018) found only significant results in fast spindle amplitude, individual peak frequency of sleep spindles is not often investigated. Furthermore, spindle characteristic analysis often analyse only N2 spindles, disregarding N3 spindles, even though previous work such as Spoormaker et al., (2011) and De Gennaro & Ferrara (2003) show that the functional networks involved in N2 and N3 spindle creation are not identical and that spindles appear to have considerably different neurophysiological characteristics and functions during different stages (Andrillon et al., 2011). Unfortunately, it has become customary in the literature to either only analyse N2 sleep spindles or analyse both N2 and N3 sleep spindles together. This is because older methods relied on manual visual inspection of the signal, and visually detecting spindles within the high amplitude slow waves of N3 was a difficult task (Cox, Hoffman, Talamini & Lucia, 2019).

Recent algorithms, such as the ones used in Pesonen et al. (2019) can detect sleep spindles in N3 with accuracy but are still rarely utilized.

Sleep spindles are also thought to have a protective effect against (sleep disturbing) external stimuli, with more sleep spindles associated with higher stimulus awakening thresholds (Peters & Jones, 1991; Elton et al., 1997; Cote, Epps & Campbell, 2000; Vyazovskiy et al., 2004; Dang-Vu et al., 2010; Schabus et al., 2012). Investigating the function of sleep spindles may be of importance in external stimulus lucid dream induction techniques. Stimulus awakening thresholds and external stimulus processing vary between persons during sleep (see 'Awakening from sleep' subheading & Chapter 2 for more), thus external stimuli techniques which use fixed stimulus properties, may fail to successfully incorporate into the dream or cause awakenings, depending on the person (Appel, Pipa, Dresler, 2017). This could be circumvented by predicting awakening thresholds through individual sleep EEG phenotyping of signal features (such as sleep spindles) and consequently modulating the stimulus properties required for dream content incorporation (see Chapters 2 and 5 for more on this). An analysis of the characteristics of the microstructure of sleep (including spindles) and their possible relation to stimulus awakening thresholds will be provided in Chapter 5.

K-complexes are the other characteristic EEG signal feature of NREM sleep. Morphologically, the K-Complex is a type of delta wave that is described as a short, large amplitude wave, that begins with a negative high voltage peak (usually > -100 μV), followed by a slower positive peak occurring between 350 and 600 milliseconds after onset and a final negative peak after around 900 ms. The K-Complex was first described by Loomis, Harvey & Hobart (1938) in the private laboratory of Alfred Lee Loomis, a corporate lawyer and JP Morgan bond-trader-turned-scientist. It was initially thought that K-Complexes reflected a response to

environmental stimuli and that they always succeeded spindles, but further research has shown that this is not the case (Colrain, 2005). K-Complexes occur in all NREM stages, are independent of sleep spindles and can be both produced spontaneously or evoked multimodally by external stimuli (Colrain, 2005). When evoked by stimuli, K-Complexes remain unaffected by stimulus properties but occur more often and produce a larger response to rarely presented stimuli (e.g., such as in an odd-ball paradigm). K-Complexes' major negative component is maximal over frontal regions (Ujszaszi & Halasz, 1988; Bastien & Campbell 1992; Sallinen, Kaartinen & Lyytinen, 1994; Cote, de Lugt, Langley & Campbell, 1999). K-Complexes (and other types delta wave bursts or 'delta-bursts') were debated to be either signs of arousal or markers of sleep maintenance (Wauquier, Aloe & Declerck, 1995; Sforza et al., 2004) with the latest position supporting a dual function (Laurino et al., 2014; Halasz, 2016). Thus, the latest position (Halasz, 2016) is that they have both homeostatic (promoting sleep) and reactive functions (protecting sleep by preventing awakenings). K-Complexes have been implicated in epilepsy as they almost always appear at the start of nocturnal epileptic episodes (Steriade & Amzica, 2003; El Helou et al., 2008). The reduction of K-Complexes has been noted in Alzheimer's disease (De Gennaro et al, 2017) and Obstructive Sleep Apnea (Huang et al., 2008; Gora, Trinder, Pierce & Colrain, 2002; Afifi, Guilleminault & Colrain, 2003). Conversely, an increase in the number of K-Complexes has been associated with Restless Legs Syndrome (RLS), whose increased number persists even after leg movement is reduced through dopaminergic drug applications (Montplaisir, Boucher, Gosselin, Poirier & Lavigne, 1996). This may explain reports of non-restorative sleep experienced in RLS patients who are on dopaminergic treatments (e.g., L-DOPA) in contrast to those on GABAergic treatments (e.g., Clonazepam), which inhibit both REM and K-Complexes, who experience improvements in sleep restoration (Saletu et al., 2001).

1.3.4 Non-REM 3 (N3/NREM3) or Slow-Wave Sleep (SWS)

The N3 stage of NREM sleep is characterized by high amplitude, low frequency delta waves of 0.5-4 Hz ("slow waves", SWs) and as such is also called slow-wave sleep (SWS). Additionally, N3 (or SWS) sleep is also termed 'deep sleep' as waking people in this stage of sleep is difficult and when people do wake up, they are usually disorientated. During this stage, parasomnias (e.g. sleep walking and sleep talking) can occur (Mahowald & Schenck, 2005). N3 sleep is thought to have a restorative role that occurs during the cortical 'down-state' (i.e., neuronal depolarization) occurrence of thalamocortical SW activity (Mackiewicz et al 2007; Maret et al 2007; Scharf et al 2008; Vyazovskiy & Harris 2013; Wisor, 2012) and a memory consolidation role during the cortical 'up-state'/neuronal hyperpolarization (Battaglia et al 2004; Destexhe et al 2007; Diekelmann & Born 2010; Tononi & Cirelli 2006). Most studies have shown that the consolidation of declarative memories (i.e., conscious or explicitly learned facts) is closely tied to the N3 stage of sleep (Gais & Born, 2004; Miyamoto, Hirai & Murayama, 2017) but (as noted above) a few studies have also implicated NREM 2 spindle activity to declarative memory consolidation (Schabus, 2004).

SWs originate from the cortex (Steriade et al., 1993; Amzica and Steriade, 1995; Csercsa et al., 2010), are regulated by the thalamus (Crunelli and Hughes, 2010; David et al., 2013) and owe their characteristic EEG morphology to the rhythmic and synchronised firing and halting of cortical neurons (Steriade et al., 1993; Nir et al., 2011). This SW activity is thought to reflect the stabilisation of synaptic connections attained during waking (Tononi & Cirelli, 2014). SWs are composed of several EEG signal characteristics such as density (SWs/minute), frequency (Hz), duration, amplitude of 'up-state' (neuronal firing) and 'down-state' (cessation of neuronal firing) and slope steepness. SW amplitude demonstrates the maximum extent of firing synchrony (Vyazovskiy et al., 2008; Nir et al., 2011), SW frequency reflects overall synaptic

load (Carrier et al., 2011) and slope steepness reflects the rapidity of the build-up and cessation of neuronal firing (Esser et al., 2007; Riedner et al., 2007). Therefore, SWs with a larger, steeper and smoother morphology indicate stronger synchronized firing, which then translates to stronger synaptic connections (Huber et al., 2007; Riedner et al., 2007). This supposition is further backed by studies which enhance SW activity through external stimulation and have demonstrated improvements in memory and executive functioning (see Zhang & Gruber, 2019 review for more on SW enhancement methodologies). As SW activity showcases how well cortical neurons engage in synchronous activity through synaptic connection, SWs are also being investigated as potential biomarkers for conditions where synaptic connectivity is affected such as in cognitive decline (Dresler et al., 2014; Yaffe et al., 2014), in IQ (Pótári et al., 2017) and its interplay with ageing (Ujma, Simor, Steiger, Dresler & Bodizs, 2019). For example, changes in NREM are considered to play a functional role in age-related cognitive decline (Mander, Winer & Walker, 2017) and this is demonstrated by age-related changes in SW parameters (Carrier et al., 2011) such as a reduction in SW density and amplitude (Dube et al., 2015, Latreille et al., 2019). Sustained SW activity at later ages is associated with better cognitive and physical health (Anderson & Horne, 2003; Mazzotti et al., 2014). High IQ is associated with a significantly attenuated, age-related reduction in SW spectral power (Pótári et al., 2017). In general, the individual morphology of slow wave activity has been found to be a consistent marker of ageing explaining up to 80% of age variance (Ujma et al., 2019).

Finally, SW activity and SW characteristics can potentially be used as an EEG biomarker for predicting stimulus awakening thresholds (SATs) and the potential of this will be investigated in Chapter 5. SW extraction algorithms used in this thesis are outlined at the end of this chapter.

1.4 REM sleep

REM sleep is the fourth and final stage of a normal sleep cycle. It is characterized by a multitude of changes, such as:

- the appearance of rapid eye movements (REMs; Aserinsky & Kleitman, 1955) which correspond to where the dreamer is looking in their dreams; muscular atonia caused by inhibition of spinal motor neurons (Jouvet & Michel, 1959);
- EEG desynchrony (Aserinsky & Kleitman, 1953) activity originating from the hippocampus;
- the appearance of ponto-geniculo-occipital (PGO) waves which are generated or propagated in the pontomesencephalic tegmentum (pons) and immediately precede eye movements (Callaway et al., 1987; Datta, 2011; Karashima et al., 2010; Amzica and Steriade, 1996; Fernandez-Mendoza et al., 2009; Martinez-Conde et al., 2009);
- autonomic response changes such as increased heart rate and blood pressure variability, respiratory irregularity and poikilothermy (i.e., incapacity to regulate body temperature) and physiological signs of sexual arousal;
- elimination of shivering and transpiration (Kelly, 1991; Nicolau et al., 2000; Parmeggiani, 1992);
- vivid and intense dreaming (Dement & Kleitman, 1957b), that is thought to arise from the appearance of synchronous thalamic, limbic and hippocampal/parahippocampal activity (Maquet et al., 1996; Poe et al., 2000; Hobson & Pace-Schott, 2002; Ribeiro et al., 2002; Cantero et al., 2003; Van der Werf et al., 2003).

The transition from NREM to REM is thought to occur due to the REM-promoting activity of cholinergic (REM-ON neurons), glutamatergic and GABAergic cell groups (Luppi et al.,

2017), and the inactivation of aminergic neurons of serotonin, noradrenaline and histamine (Brown & McCarley, 2008). Conversely, the transition from REM to NREM is thought to occur due to the activity of REM suppressive, monoaminergic neurons, often termed as REM-OFF neurons, which are located in the midline zone of the brainstem raphe nuclei, and a more lateral band-like zone in the rostral pons/midbrain junction that includes the nucleus locus coeruleus, the reticular zone and the peribrachial zone (McCarley, 2007).

The REM-promoting cholinergic neurons, whose mechanisms are key in initiating and coordinating REM sleep (McCarley, 2007), are situated in the pedunculopontine and laterodorsal tegmental nuclei (PPT/LDT). The PPT/LDT cholinergic neurons, through the activation of the basal forebrain are also considered key in producing the characteristic REM EEG activity (Luppi et al., 2012). The EEG resemblance between REM and waking is thought to occur through the release of acetylcholine, which during REM, reaches the level of waking cholinergic activity (Vazquez & Baghdoyan, 2001). In contrast to waking activity, the sublaterodorsal nucleus (in the pons) activates the ventromedial medulla groups that regulate muscle tone by inhibiting spinal motor neurons and thus prevents us from acting out our dreams (Wigren & Porkka-Heiskanen, 2018). Dysfunction in this area disrupts sleep muscle atonia and leads to REM sleep behaviour disorder: a disorder wherein dreams are acted out and dreamers may end up injuring themselves or others as a result.

During REM, brain activity in subcortical and midline areas such as the anterior cingulate cortex (Braun et al. 1997; Buchsbaum et al. 1989; Nofzinger et al. 1997), the amygdala and the limbic–paralimbic regions (Braun et al. 1997; Nofzinger et al. 1997), the associative visual areas (Braun et al. 1997, 1998; Madsen et al. 1991) and the pons is significantly more active during REM sleep than during wakefulness (Braun et al. 1997), while frontal activity is

significantly decreased when compared to wakefulness (Braun et al. 1997; Madsen et al. 1991). This change in brain activity is thought to give rise to the vivid dream mentation that is experienced during typical REM sleep (Braun et al. 1998). The neurobiology of dreams is further discussed in Chapter 2.

REM sleep duration is very short during the first cycle of sleep, lasting only a few minutes, but increases with each successive cycle with later REM cycles lasting approximately thirty minutes (McCarley, 2007). In most mammals, REM sleep duration massively decreases with age, with new-born babies spending most of their life in REM sleep, and then a gradual reduction is observed that plateaus (when controlling for mental and physical health issues) when developmental maturity is reached (Floyd, Janisse, Jenuwine & Ager, 2007; Blumberg & Seelke 2010).

Sleep deprivation studies have demonstrated that inhibiting REM sleep leads to an REM rebound effect, wherein REM onset occurs earlier in subsequent sleeps and subjects spend a higher percentage of the night in REM sleep (Dement, 1960; Nielsen et al., 2005). Nielsen et al.'s (2005) study demonstrated that REM deprivation of 30 minutes in one night can lead to 35% increase in REM sleep the following night, as well as an increase in dream intensity. The REM rebound effect commonly occurs in persons taking certain types of sleeping aids, patients with sleep apnoea after the first few nights of being placed on continuous positive airway pressure (CPAP; Verma et al., 2001) and following the use of various REM-suppressant drugs such as alcohol (Ebrahim et al., 2013). Thus, the REM rebound effect is arguably pointing that REM is a necessary physiological need for the organism that needs to be 'caught up' if missed.

A lucid dream technique that may in part work through the REM rebound effect is the Wake-Back-to-Bed (WBTB) method. WBTB is a lucid dream induction technique wherein practitioners set their alarm 1-2 hours before their normal waking time, in the hopes of interrupting their REM sleep (which is longer and more stable in later cycles) and then stay awake for a brief time before falling asleep while practising other lucid dream techniques (Stymbrys et al., 2012). It is thought that the brief REM interruption and awakening subsequently leads the person to transition back to REM quickly with a state that is optimal for lucid dreaming (i.e., while the cortex is more activated due the brief awakening). This technique is discussed in more detail in Chapter 2 and is utilized in study Chapters 4 and 5.

It is largely accepted in the sleep science literature that REM sleep plays an important part in spatial and emotional memory consolidation as well as in some types of procedural memory, but additional functions have been assigned, such as: facilitating cortical plasticity (Bridi et al., 2015; Sterpenich et al., 2014); facilitating learning and memory through selective pruning and maintaining newly formed synapses implicated with specific types of motor learning (Li, Ma, Yang & Gan, 2017); restoring aminergic cell/receptor function (Siegel & Rogawski, 1988); and increasing general creativity (Cai, Mednick, Harrison, Kanady & Mednick, 2009; Wegner, Gais, Haider, Verleger & Born, 2004). Studies investigating the effect of sleep on procedural memory have shown that REM sleep is increased following implicitly learned information (Smith et al., 2004) and following the learning of complex and/or novel procedural memory tasks (Smith et al., 2004). The latter demonstrates a dissociation between simpler and complex procedural memory tasks as simpler procedural memory tasks seem to implicate N2 sleep more, in particular, N2 sleep spindle activity (Fogel & Smith, 2006; Laventure et al, 2016; Morin et al., 2008; Nishida & Walker, 2007). Studies on emotional memory and sleep, by investigating the effect of neutral vs emotional content, have implicated REM sleep in the

consolidation of emotional memories (Alger & Payne, 2016; Hu et al., 2006; Deliens, Gibson & Peigneux, 2014). It has to be mentioned that the notion that REM is implicated in certain types of memory formation (such as emotional and spatial formation) and consolidation has been contested by other authors' findings and through critiques of some of the methodologies employed to study the function of sleep (Diekelmann and Born, 2010; Siegel, 2001; Horne, 2013; Vertes, 2004; Rasch, Pommer, Diekelmann & Born, 2009; Benington & Heller, 1994; Zhang et al., 2014). A criticism that persists against the causal inference that REM is implicated in emotional and spatial memory consolidation, is often related to the methodology that is traditionally used to study REM function (Peever & Fuller, 2017). Specifically, arguments such that REM sleep deprivation also impacts NREM sleep (Benington & Heller, 1994) and that sleep deprivation paradigms cause stress (Zhang et al., 2014), show that it is difficult to infer causality. While the methodological criticisms are valid, a later optogenetic study on rats by Boyce, Glasgow, Williams and Adamantidis (2016) supports the emotional and spatial memory consolidation REM function hypothesis. Specifically, the authors used optogenetic modulation, during REM, to temporally switch off medial septum GABA cells which drive hippocampal theta activity (implicated in memory consolidation) without disturbing sleeping behaviour. The authors found that this led to an erasure of novel object place recognition and an impairment of fear-conditioned contextual memory (Boyce et al., 2016). Finally, with regard to putative REM functions, as REM sleep is mostly associated with vivid dreaming, most other theories on its function are closely tied with theories on the function of dreaming. Theories on the function dreaming are discussed in Chapter 2. One further thing to consider, when attempting to understand REM sleep, is that two different types of REM sleep are thought to exist: tonic and phasic REM. Tonic REM (tREM) is characterised by a widespread, low-voltage, fast cortical activity with hippocampal theta, a decrease in neck and chin EMG amplitude, brain temperature elevation and absence of REMs (Baust et al., 1964; Pessah & Roffwarg, 1972;

Rechtschaffen, 1978) while phasic REM (pREM) is characterized by REMs which are associated with PGO waves (Callaway et al., 1987; Datta and Hobson, 1994; Lim et al., 2007), middle-ear-muscle activity, extra-ocular phasic integrated potential, and cardio-respiratory irregularities (McCarley & Hobson, 1975; Sallinen et al.,1996) and an even further increase in muscle atonia when compared to tREM (Ermis, Krakow & Voss, 2010). pREM is postulated to support information exchange between hippocampus and neocortex (Datta et al., 2004; Karashima et al., 2005; Montgomery et al., 2008). Differences in awakening thresholds exist between phasic and tonic REM sleep (Sallinen et al., 1996; Ermis et al., 2010), with pREM being more similar to SWS awakening thresholds and tREM closer to NREM 2 awakening thresholds. In addition, stimuli such as audio, when presented during tREM, seem to elicit a residual cortical activation, whereas during pREM, there seems to be almost no stimulus reactivity (Sallinen et al., 1996; Takahara et al., 2002; Wehre et al., 2007). Due to this, the function of tREM, at least from an evolutionary point of view, is thought to provide a window of opportunity wherein the organism is able to detect threatening environmental stimuli (Voss, 2010). Understanding the differences in stimulus processing and awakening threshold between tREM and pREM should be of particular importance in lucid dream techniques which utilize external stimuli (see more about this in subheading 1.1.4 below and in Chapter 2).

1.5 Awakening from Sleep

The reticular activation system (RAS) is responsible for regulating vigilance and is formed by cell groups in the basal forebrain, hypothalamus and brain stem, which send their projections to the cortex and other sub-cortical parts of the brain (Wigren & Porkka-Heiskanen, 2019). RAS projections use the neurotransmitters noradrenaline (NA; locus coeruleus), serotonin (5HT; raphe nuclei), histamine (tuberomammillary nuclei of posterior hypothalamus), orexin

(lateral hypothalamus) and gamma aminobutyric acid (GABA; Basal forebrain, parafacial nucleus and cortical cells containing neuronal nitric oxide synthase).

The subjective experience of waking up differs between stages. When one is awoken from REM sleep, one usually reports feeling more sluggish, and is more likely to feel disorientated and confused than when awoken from NREM stages (Wang-Weigand et al., 2007). Subjects are most easily awoken in NREM 1, followed by NREM 2, tREM, NREM 3 and pREM (Sallinen et al., 1996; Ermis et al., 2010). The increased difference in awakening thresholds between pREM and tREM is thought to be due to the increase in widespread thalamocortical synchronised activity of pREM when compared to tREM (Wehrle et al., 2007). In addition to the difference found in awakening thresholds and brain reactivity to external stimuli during the different stages, awakening thresholds vary according to sleep cycle (Busby, Mercier & Pivik, 1994; Zepelin, McDonald & Zammit, 1984) and several individual differences exist, such as age (Zepelin, McDonald & Zammit, 1984; Busby, Mercier & Pivik, 1994), sex (Formby, 1967; Poitras et al., 1973; Zepelin, McDonald & Zammit, 1984), and dream recall frequency (Ruby et al., 2013; Ruby et al., 2013; Eichenlaub et al.,2014; Vallat et al., 2017). In addition, the semantic quality of the stimuli also plays a significant role (Oswald et al.,1960; Langford et al., 1974; Beh & Barrat, 1965; McDonald et al., 1975; Voss & Harsh, 1998). For a more detailed account on awakening thresholds and stimulus processing in sleep, see Chapter 2.

Awakening from sleep and micro-arousal (MA) from sleep are two distinct phenomena. Whereas arousal from sleep that leads to an awakening and denotes an interruption of sleep in a decisive and non-reversible way, in an MA, there is no awakening, despite various combinations of EEG de/synchronization and/or autonomic and/or behavioural responses (Halasz et al. 1979). MAs can be autonomic in origin (i.e., heart rate variability, blood pressure

& muscle tone) and precede EEG de/synchronisation, or may be entirely autonomic in nature (without the subsequent EEG changes) and hence such an MA would be referred to as 'autonomic arousal' (Martin et al., 1997; Pitson & Stradling, 1998). MAs which cause a behavioural response (i.e., reflex motor responses such as the startle response or augmented breaths) with low-voltage fast-EEG activity are referred to as 'behavioural arousal' (Moruzzi & Magoun, 1949). 'Cortical arousal' is another type of MA which, according to the Sleep Disorders Atlas Task Force of the American Sleep Disorders Association (ASDA; Bonnet et al., 1992), is characterised by an EEG pattern shift to alpha (8-13 Hz) or higher than 16 Hz for at least one second (Atlas Task Force, 1992). Finally, a 'subcortical arousal' is a type of MA wherein, autonomic (Pitson et al., 1994; Carley et al., 1997; Martin, Engeman, Kingshott & Douglas, 1997) or behavioural activation (Lijowska, Reed, Mertins Chiodini & Thach, 1997; McNamara, Wulbrand & Thach, 1998; McNamara, Lijoowska & Thach, 2002), is associated with an EEG activation that is slower than alpha and usually comes in the form of bursting delta (D-bursts) and K-complex (K-bursts) activity (Halasz, 1998; Quattrocchi, Shapiro, Verrier & Hobson, 2000; Sforza, Jouny & Ibanez, 2000; Busha et al., 2001).

Further research into MA states and in general the process of awakening, particularly during REM sleep, may improve lucid dream induction techniques, which use external stimuli to cue the dreamer that they are dreaming. After all, lucid dreaming is thought to be an intermediate state both phenomenologically and neurobiologically between REM and wakefulness (Voss, Holzmann, Tuin & Hobson, 2009; Hobson, Pace-Schott, & Stickgold, 2000; Voss, Schermelleh-Engel, Windt, Frenzel & Hobson, 2013). For a further discussion on the phenomenological and proposed neurobiological profile of lucid dreaming, see Chapter 2. In addition, being able to predict response to an external stimulus will not only prevent awakenings during attempts to induce lucid dreaming (Appel, Pipa, Dresler, 2018) but also

MA-causing stimuli (tailored to the individual), may be desirable in order to 'break' the thalamic gates open momentarily, and thereby successfully incorporate stimuli into the dream content (Solomonova & Carr, 2019; See Chapter 2 for more on external stimuli techniques, Chapter 2 on external stimuli processing during sleep).

1.6 Polysomnography, sleep data analysis & equipment/software used

1.6.1 Polysomnography

The transition from waking to sleep and its distinctive stages is made apparent through the procedure of polysomnography (PSG). The PSG procedure usually includes the recording of EEG, electrooculography (EOG), electromyography (EMG) as well as additional physiological parameters such as respiration recordings or electrocardiography (ECG) (Berry et al*.,* 2016).

1.6.2 History of Polysomnography

Historically, the electrophysiological exploration of the human brain was started by Hans Berger (1929), 54 years after Richard Caton first recorded electrical brain activity of rabbits and monkeys (Caton, 1875). As well as discovering the alpha rhythm, Berger was the first to show electrophysiological differences between wakefulness and sleep (Deak & Epstein, 2009). Following this, sleep science took off in the 1930s with two main research groups, one from Harvard University and the other from the University of Chicago (UoC); both conducting pioneering work in the field (Deak & Epstein, 2009).

Harvey, Hobart, Loomis and colleagues in Harvard, were the first to describe the signal features of NREM sleep (sleep spindles, K-Complexes, delta waves), categorizing sleep into five stages: Stage Alpha containing alpha rhythm trains, varying in length and appearance of slow eye

movements); Stage B containing low voltage potential changes and reduction/elimination of alpha activity; Stage C containing sleep spindles accompanied by "random" or delta brain activity; Stage D containing spindles and random/mixed activity, with delta activity progressively increasing until reaching; Stage E, containing random/mixed activity. These Harvard researchers were also the first to use sensors in addition to EEG, to measure heart rate and respirations (Loomis, Harvey & Hobart, 1937).

UoC researchers, Blake & Gerald (1937), were the first to research awakening thresholds using external stimuli of varying types, lengths and intensities. They also discovered that certain sleep EEG signals, such as spindles and alpha trains, were best attained from different scalp locations (Blake & Gerald, 1939). In the 1950s, two other researchers from UoC, Professor Nathaniel Kleitman and his graduate student Eugene Aserinsky, were the first to discover and conduct extensive research on REM sleep (Aserinsky & Kletiman, 1953). This UoC group were the first to use EOG in PSG recordings and through this method were able to distinguish between slow eye movements and rapid eye movements. They were also the first to note that it was during REM that participants were most likely to report dreams and that during this phase, awakenings produced the most perceptually vivid dream reports. In addition, Kleitman & William Dement were the first to do full night EEG recordings, and by doing so they discovered, the human sleep cycle (Dement & Kleitman, 1957).

1.6.3 Current systems of sleep scoring and PSG electrode derivations

After the discoveries from Harvard University and UoC research groups, the growing need for establishing universally accepted methods of sleep monitoring and scoring, led to the creation of the Association for the Psychophysiological Study of Sleep, in 1960 and subsequently, to the publishing of the *Manual of Standardized Terminology, Techniques and Scoring System*

for Sleep Stages of Human Subjects (Rechtschaffen & Kales, 1968). The Rechtschaffen & Kales manual (R&K manual) scored sleep in 30s epochs and provided a thorough description of sleep stage scoring, using EEG, EOG and ECG recordings and technical considerations. Nowadays, sleep onset/end and the sleep stages are scored using the widely accepted rules set out by the R&K manual or the newer *American Academy for Sleep Medicine Manual (AASM) for the Scoring of Sleep and Associated Events* (Berry et al*.,* 2016). The AASM manual is an improvement to the R&K manual in many ways (Himanen & Hasan, 2000): It is continually updating every few years with the latest findings in sleep science; it includes a system for scoring arousals; it provides instructions for scoring abnormal sleep and paediatric and geriatric sleep, as opposed to the R&K manual, which only described adult healthy sleep; and includes more EEG electrode montage derivations (Deak & Epstein, 2009). According to the latest AASM, the recommended EEG derivations are F4-M1, C4-M1 and O2-M1, thus, EEG is obtained from frontal, central and occipital regions. The optimal AASM EEG derivations are chosen as the ideal way to score sleep for the following reasons: Central regions provide the optimum location to measure sleep spindles (McCormick, Nielsen, Nicolas, Ptito & Montplaisir, 1997; De Gennaro, Ferrara & Bertini, 2000a; De Gennaro, Ferrara & Bertini, 2000b); frontal regions are optimum for K-Complex detection (McCormick et al., 1997; Happe et al., 2002) and delta wave activity (Werth, Achermann & Borbely, 1997; Happe et al., 2002); while occipital regions are optimum for measuring alpha activity (Adrian & Matthews, 1934). For EOG recordings, the recommended AASM EOG electrode derivations are E1-M2 and E2-M1 with E1 being placed 1 cm below the left outer canthus and E2 placed 1 cm above the right outer canthus. The EOG derivations are used to score REM sleep and inspect when slow-eye movements start occurring (which most frequently occurs in N1 sleep). Regarding PSG EMG recordings, the AASM recommends placing three electrodes: One in the midline 1 cm above the inferior edge of the mandible, One 2 cm below the inferior edge of the mandible and 2 cm

to the right of the midline and one 2 cm below the inferior edge of the mandible and 2 cm to the left of the midline (Berry et al., 2016). These EMG derivations are optimal for detecting muscle atonia progression.

1.6.4 Issues with traditional PSG recordings and scoring

PSG recordings are costly, require clinical admission, create long waiting lists (Flemons et al., 2004) and require technical support for PSG sensors to be applied/removed coupled with overnight monitoring and manual record scoring. Additionally, the multiple sensors that have to be attached on the scalp, face and body of patients/participants through the duration of the sleep study can be uncomfortable (figure 1.3).

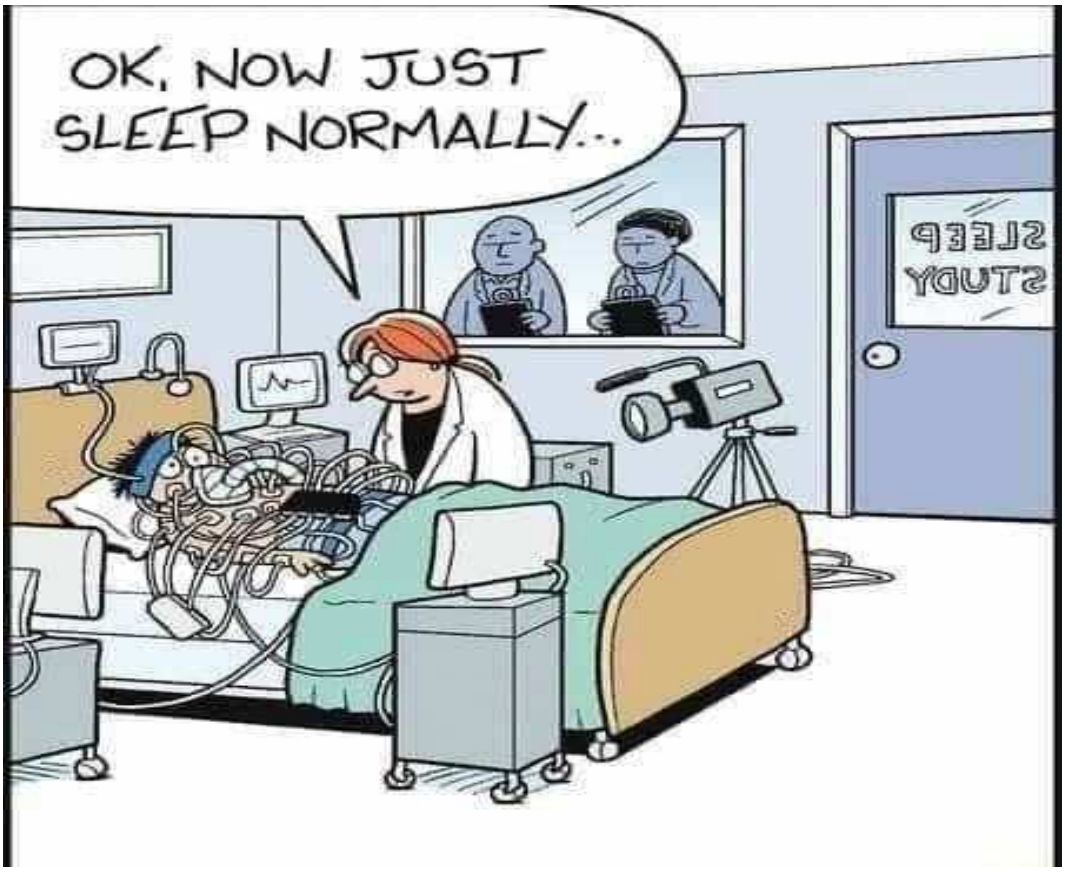

Figure 1.3. A comical, but, fairly accurate representation of a polysomnographic (PSG) study. Drawing made by Mark Paris and used in the thesis with the author's permission. The drawing was taken from the author's website www.offthemark.com.

Furthermore, manual scoring and analysing of PSG readings can be a burdensome task, requiring two to four hours to score an entire night's sleep data (Ronzhina et al., 2012) and is prone to scorer subjectivity with an overall inter-rater agreement of about 81-83% (Danker-Hopfe et al., 2009; Ruehland et al., 2011; Rosemberg & Van Hout, 2013). Rosemberg & Van Hout's (2013) study of more than 2500 scorers demonstrates that scoring discrepancies vary between stages, with REM, N2 and W scoring the highest agreement (>80%), followed by N3 (67%) and N1 (53%). The discrepancies mainly occur during the transitional phases between stages as sleep staging rules attempt to characterize a continuous physiological process. Complexities of conducting PSG studies are amplified further in lucid dreaming research due to high induction failure rates, difficulty finding experienced lucid dreamers, long briefing sessions and an increased requirement for the researcher to stay awake monitoring participant throughout the whole night (Appel, Pipa & Dresler, 2018). For example, in the case of external stimulation LD techniques the researcher is required to stay awake monitoring participant, scoring sleep in real-time and then manually initiating stimulation when appropriate (usually when REM sleep is detected).

1.6.5 Sleep stage scoring methodologies

Thus, there is a growing need for new PSG technologies and the automatization of PSG sleep scoring in traditional sleep medicine, sleep and lucid dream research. Recent developments in automatic sleep scoring are producing highly accurate automatic detection and scoring of sleep stages through computer algorithms coupled with a reduction in the number of EEG sensors required down to sometimes, a single channel of EEG (e.g., Imtiaz & Rodriguez-Villegas, 2014; Kaplan et al., 2014). Most of the algorithms are offline but others have online scoring capabilities (e.g., Patanaik, Ong, Gooley, Ancoli-Israel, & Chee, 2018). The online scoring algorithms could provide automatic stimulus presentation capabilities for lucid dreaming

induction (LaBerge et al., 1995; Mota-Rolim, Pavlou, Nascimento, Fontenele-Araujo & Ribeiro, 2019), Targeted Memory Reactivation (TMR; eg., Rudoy et al., 2009; Oudiette et al., 2013) and SW enhancing (Ong et al., 2016; Papalambros et al., 2017; Marshall et al., 2006; Ngo et al., 2013) paradigms.

With the recent increase in computational power, a variety of machine learning algorithms have been investigated for automatic sleep scoring. Machine learning algorithms that have been used include deep learning (Patanaik et al., 2018), support vector machine (Koley & Dey, 2012), , artificial neural networks (Chapotot & Becq, 2010; Anderer et al., 2010; Sinha, 2008; Zoubek et al., 2007), learning vector quantization (Zhovna et al., 2008), rule and case based reasoning (Anderer et al., 2005; Anderer et al., 2010; Park et al., 2000), neurofuzzy classifier (Estrada et al., 2004), extreme learning machine (Sun et al., 2017) and hidden Markov models (Doroshenkov, Konyshev & Selishchev, 2007). These machine learning models exhibit an accuracy between 75% and 95% when compared to expert human scoring (Patanaik et al., 2018), especially in the sleep scoring of healthy population (Sun et al., 2017; Boostani, Karimzadeh & Nami, 2017; Lacourse, Delfrate, Beaudry, Peppard, & Warby, 2019). Some sleep scoring techniques even use non-EEG psychophysiological measures, such as heart rate, galvanic skin response/electrodermal activity (GSR/EDA; Jung et al., 2015; Kobayashi et al. 2010) and body movement. These measures have been individually used to score sleep (e.g., Mitsukura, Fukunaga, Yasui, & Mimura, 2020) or have been used in combination (e.g., Tanida, Shibata & Heitkemper, 2013; Fonseca et al., 2015; Willemen et al., 2014). The logic behind using heart-rate readings is that heart-rate varies between wake and sleep and between each sleep stage. In general, low-to-high frequency (LF:HF) ratio of the ECG signal decreases when one falls asleep (Scholz et al., 1997) due to bodily recovery processes, a decrease in basal metabolic rate (Townsend, Prinz & Obrist, 1973) and the parasympathetic nervous system

activation during sleep (Mitsukura, Fukunaga, Yasui & Mimumura, 2020). REM sleep is distinguished from NREM by a significant LF: HF increase that is caused by an increase in basal metabolic rate and sympathetic nervous system activation (Boudreau et al. 2013; Penzel et al., 2016). As for using GSR in automatic sleep scoring, studies such as Kobayashi et al. (2003) demonstrate differences in GSR peaks and sweat ratein N2, N3 and REM sleep, with lowest GSR peak frequency (peaks per epoch) being in REM and highest in N3 (see figure 1.4). This result was also repeated in Sano, Picard & Stickgold (2014)

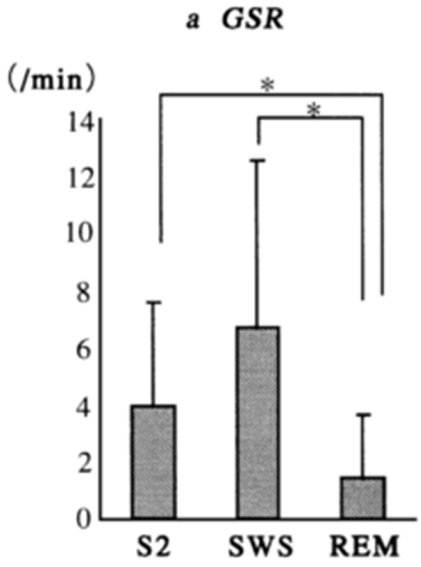

Figure 1.4. Average Galvanic Skin Response (GSR) peaks per minute differences between NREM 2 (S2), NREM 3 (SWS) and REM sleep. Taken from Kobayasi et al (2003).

This finding was subsequently implemented in an GSR N3 sleep scoring algorithm, developed by Jung et al. (2015). The algorithm produced highly accurate results in detecting N3 as the authors reported an average sensitivity of 74.6%, an average specificity of 98.0%, and an average accuracy of 96.1% (Jung et al., 2015).

One example of using non-EEG sensors to score sleep onset used in dream science is the hand-worn device Dormio, first developed by MIT researcher Adam Haar Horowitz as part of his

MSc thesis (Haar Horowitz, 2019). The Dormio device (figure 1.5) is used to detect the hypnagogic state and to influence hypnagogic imagery through the use of auditory cues. The device tracks sleep onset through the use three physiological indicators sensors: EMG, GSR and PPG. Participants are asked to gently close their hand while falling asleep in order for the EMG sensor to accurately monitor and detect progressive muscle loss caused by falling asleep. The Dormio device takes inspiration from the 'steel ball technique' (Haar Horowitz, 2019). In the 'steel ball technique', one is instructed to hold a steel ball at the edge of the bed while falling asleep. Once sleep onset is reached the progressive muscle atonia causes the grasp to loosen, causing the steel ball to fall to the ground which wakes the user. This technique was reportedly used by Thomas Edison and Salvador Dali, who utilised hypnagogic dreams as inspiration and problem-solving solution to their work. Alongside the EMG sensor, the GSR and PPG sensors are used to confirm when a participant enters the hypnagogic state, as they have been found in past research to accurately detect this state (Herlan, Ottenbacher, Schneider, Riemann, & Feige, 2019; Ogilvie, 2001). Results in Horowitz et al. (2018) and Horowitz (2019) suggest that Dormio increases direct inclusion of target words in reported dream content which improved performance on a range of creativity tasks related to these targets.

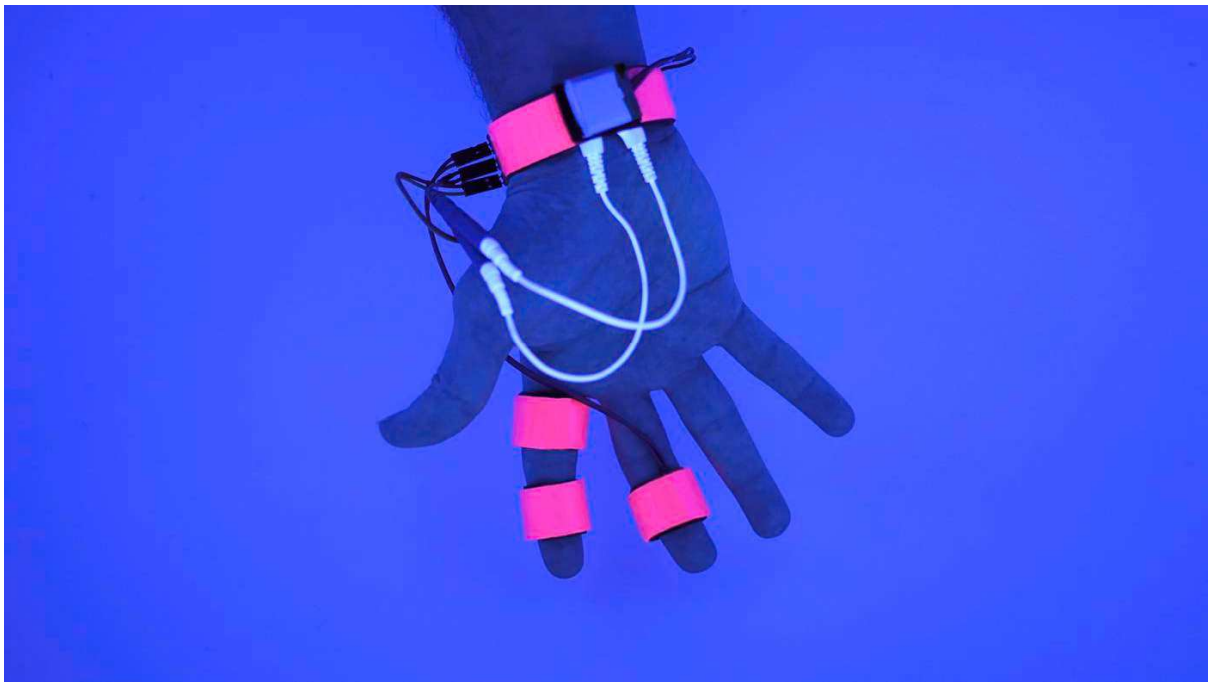

Figure 1.5. Dormio hand-worn device developed by MIT. Dormio includes an accelerometer, wrist electromyogram (EMG) sensor and photoplesmograph (PPG) finger sensor to measure heart-rate galvanic skin response (GSR) sensors located at the fingers. Image taken from https://www.media.mit.edu/projects/sleep-creativity/overview

1.6.6 Sleep wearables

In the recent years, small wearable technology in the form of actigraphy and EEG wearables that measure sleep are increasingly being used in research and are gaining consumer usage and adoption (Grifantini, 2014). For example, actigraphy watches which utilise accelerometer readings and PPG sensors to score sleep, have been used for decades in sleep research to study a variety of sleep-related areas such as sleep disorders and circadian rhythm sleep-wake disorders (Smith et al., 2018). These research-grade actigraphy devices are now widely been used by the public as they are now implemented in fitness tracking watches (e.g., Fitbit watches) and even in smart-ring form (e.g., the Oura ring). Several of the commercially available fitness trackers, such as Fitbit and Apple Watch exhibit good sleep scoring ability when compared to human scoring using golden standard of PSG lab equipment which utilises EEG, EMG and EOG readings (Haghayegh, Khoshnevis, Smolensky, Diller & Castriotta, 2019; Roomkham et al., 2019). Specifically, Haghayegh et al. (2019) meta-analysis shows that

the latest Fitbit models exhibit a sleep scoring accuracy between 0.81% - 0.91%, sensitivity values between 0.95 - 0.96, and specificity values between 0.58 - 0.69.

In the recent years, in addition to consumer actigraphy devices, consumer EEG wearables have been released, such as Zeo, Neuroon, SmartSleep Deep Sleep Headband, Dreem and Hypnodyne ZMax. Zeo was the first consumer EEG sleep tracking device, but the company shut down in 2013 due to business-related issues (Grifantini, 2014). These consumer EEG wearables are worn on the forehead utilise a very small number of electrodes (e.g., typically two to four), which are usually placed at the frontal brain areas. Currently. out of all the consumer available devices, Hypnodyne ZMax is the only research-ready equipment that can be used for lucid dreaming research (Mota-Rolim, Pavlou, Nascimento, Fontenele-Araujo & Ribeiro, 2019) and is used for the work carried out in Chapter 5 of this thesis.

Specifically, Hypnodyne Zmax (http://hypnodynecorp.com/) is a small EEG home sleep monitor device (figure 1.6) that is capable of recording EEG activity, heart rate (PPG) temperature, room illumination and noise levels.

Figure 1.6. The front and back side of Hypnodyne ZMax. On the back side the photoplesmograph (PPG) sensor can be seen in the middle, encased in a soft plastic cover. In addition, the for clip-on inserts for ZMax's proprietary disposable electrode patch can be seen surrounding the PPG sensor.

The device has offline sleep scoring and online REM scoring capabilities (through a proprietary sleep staging algorithm) and through this algorithm it can provide visual (through two LEDs), vibrotactile (through a vibro-motor encased inside the device) and auditory stimuli (through

connected computer's speakers/headphones) when REM periods are detected. Zmax requires at least three hours of recording for the online REM algorithm to begin detecting REM epochs and stimulation are presented within one second after a 30 second REM epoch has been detected.

Proprietary disposal electrode patches (http://hypnodynecorp.com/) containing solid conductive hydrogel are attached to the device to provide EEG recording (figure 4). Hypnodyne Zmax is worn slightly above eyebrow level and EEG activity is obtained through the electrode patch's two active electrodes placed near forehead temples, around areas AF7 and AF8. Two reference electrodes are located vertically at the FPz area (figure 1.7).

Figure 1.7. Hypnodyne Zmax propriety disposable clip-on EEG electrodes

The device uses forehead reflectance photoplethysmography (PPG) to monitor heart rate. Room illumination and noise level are measured through the device's photo and sound sensor, respectively. Skin temperature is acquired from the forehead, through the device's temperature sensor. Body movements are recorded through the device's three-axis accelerometer.

Hypnodyne comes with three separate software programs: HDRecorder, HDScorer and HDServer. HDRecorder software allows for real-time monitoring of EEG, temperature, light, sound, accelerometer sensor activity through its graphical User Interface (UI) after first

establishing connection in the HDServer software between ZMax and the computer (through USB signal receiver dongle). Stimuli protocols can be set either through the software's UI options or through loading a custom JavaScript script file. Due to the complexity of the protocol a custom Javascript code was created for the purpose of this study. The saved recordings can be inspected offline through the HDscorer (figure 1.8) software which allows for manual hypnogram scoring and for sending the EEG sleep recording to Hypnodyne's server for automatic scoring. In this study, the sleep recordings were first sent for automatic scoring and then each epoch was visually inspected and corrections to the hypnogram where made when there was a disagreement with the automatic scoring algorithm.

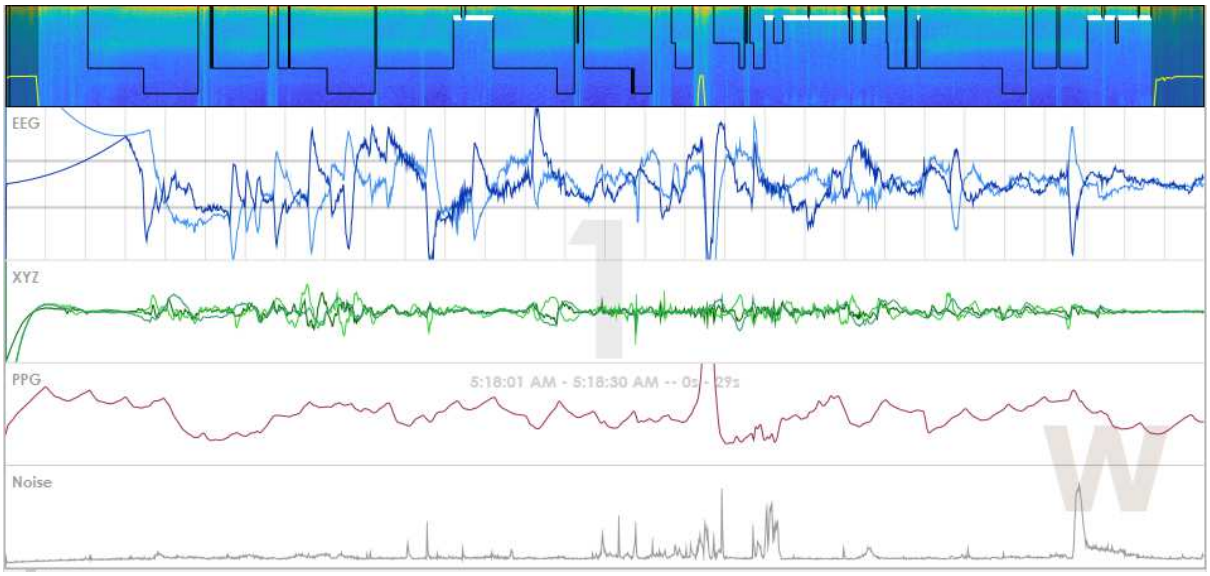

Figure 1.8. HDScorer's UI. The top row shows whole recording spectrogram, hypnogram and light levels. Second row is a 30s epoch of EEG activity. Third row is a 30s epoch of accelerometer activity. Fourth row displays heart rate activity from the PPG sensor (artifacts are present as movement occurred in this epoch). Fourth row displays 30s noise level activity

1.6.7 Feature extraction algorithms

In order for EEG biomarkers to be used for diagnosing, tracking and predicting disorders, conditions and therapeutic outcomes, where sleep is involved, automatic signal processing algorithms should not only rely on scoring sleep stages (i.e., the macrostructure of sleep) but

also, as evident from the previous sections, they should accurately extract, categorize and analyse sleep EEG microstructure. To this extent, EEG feature extraction algorithms have been developed to perform automatic sleep scoring, extract and categorize sleep features such as sleep spindles, K-Complexes, SWs and to perform spectral and band power analysis on sleep epochs and stages (see Patanaik et al., 2018 for an outline of some of these methods).

The work carried out for this thesis and described in Chapter 5 utilises the YASA algorithm (*Yet Another Spindle Algorithm*) to analyse sleep EEG macro/microstructure (Vallat & Jajcay, 2020). YASA is an open-source Python package dedicated to sleep microstructure analysis that uses validated algorithms to detect spindles, slow-waves, REMs and to spectral analysis. The YASA's sleep spindle algorithm uses a modified version of the A7 sleep spindle algorithm (Lacourse, Delfrate, Beaudry, Peppard & Warby, 2018). The algorithm outputs overall sleep spindle density and the start and end time, duration, amplitude, frequency, Root Mean Square (RMS), absolute and relative power, oscillation and symmetry properties for each detected spindle (table 1.1). Oscillation properties of a spindle refer to the number of positive peaks within a spindle, whilst symmetry refers to the position of the highest peak, measured from 0 to 1 with 0.5 denoting that the highest peak is found in the middle of the spindle.

Table 1.1: Example of YASA output. Table includes the following EEG characteristics for two detected spindles; Start and end time of spindle, duration, amplitude, Root Mean Square (RMS), absolute power, relative power, frequency, oscillations and symmetry

Start	End	Duration	Amplitude	RMS	AbsPower	RelPower	Frequency	Oscillations	Summetry
3.32	4.06	0.74	81.80	19.65	2.72	0.49	12.85	10	0.67
13.26	13.85	0.59	99.30	24.49	2.82	0.24	12.15	7	0.25

The YASA slow-wave detection algorithm implements Massimini, Huber, Ferrarelli, Hill & Tononi's (2004) and Carrier et al's. (2011) SWA detection and feature categorisation algorithm. YASA's slow-wave algorithm outputs the following values: start and end times of

each detected slow wave; positive, negative to mid-negative and mid-crossing (positive) duration; its overall duration; the amplitude of the positive, negative peak, peak-to-peak amplitude and slope (figure 1.9).

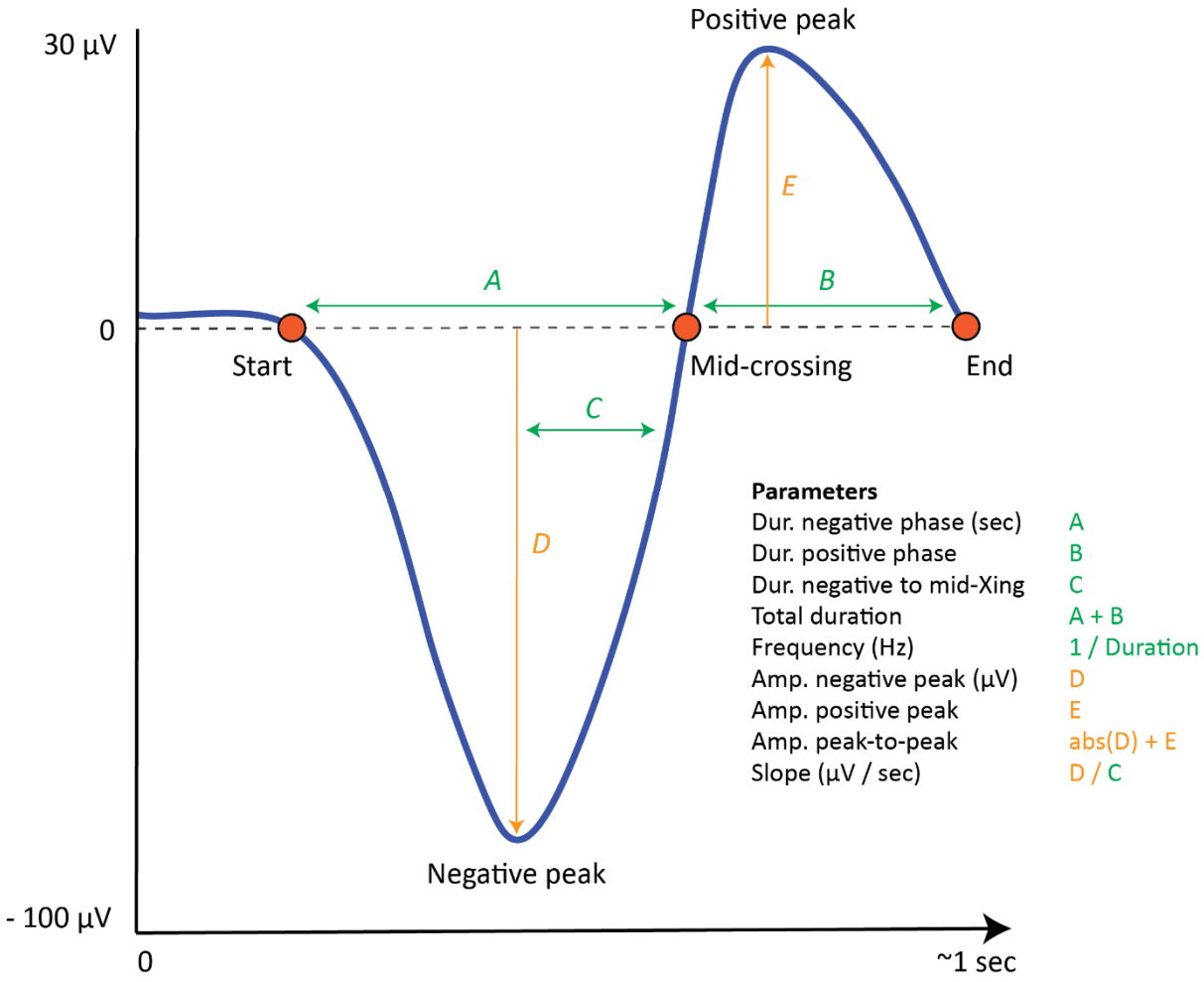

Figure 1.9. Graph depicts a slow-wave and the slow-wave parameters that the YASA's algorithm outputs. Taken from YASA's Github page (https://github.com/raphaelvallat/yasa/blob/master/notebooks/06_sw_detection.ipynb).

REMs in YASA are detected using an algorithm adapted from Agarwal, Takeuchi, Laroche & Gotman (2005) and Benjamin et al (2016). The algorithm outputs duration, amplitude and slop characteristics of REMs. YASA's spectral analysis algorithm is also used in this thesis to perform band power analysis (absolute and relative band power) for each sleep stage using both Welch and the multi-taper spectral estimation methods. YASA also offers a variety of

nonlinear analysis metrics included fractal dimension analyses such as Irregular Resampling Auto-Spectral Analysis (IRASA; Wen & Liu, 2016), Detrended Fluctuation Analysis (DFA), Lempel-Ziv complexity, Petrosian, Katz and Higuchi. Nonlinear analysis of entropy included permutation, spectral, approximate, sample and Singular Value Decomposition (SVD).

Non-linear dynamics of the EEG signal provide insights into the dynamical nature and variability of the brain signal (Ma, Shi, Peng & Yang, 2017). For example, using entropy-based methods one can quite clearly distinguish NREM 3 from other sleep stages or wake due to the fact that NREM 3 is characterised by its highly synchronous delta-wave neuronal firing nature. Hence, a significant decrease in entropic measures can be observed (Ma, Shi, Peng & Yang, 2017). Conversely, the REM stage and the wakefulness, with their highly asynchronous and mixed signal EEG activity, exhibit much higher entropic values (see figure 1.10, below for a representation of this).

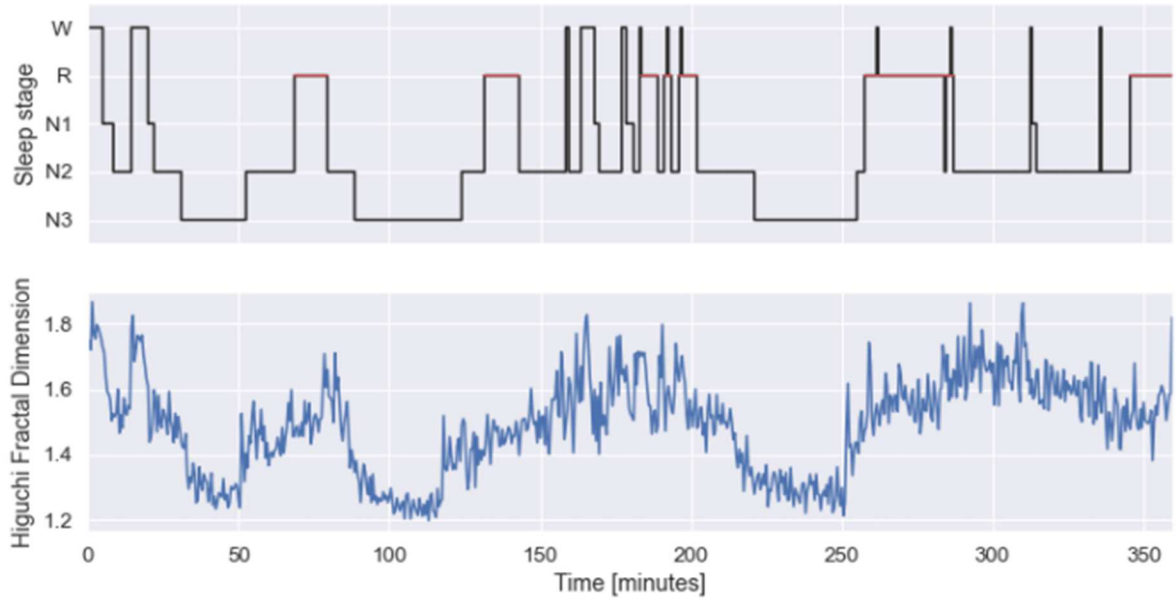

Figure 1.10. Higuchi Fractal Dimension (HFD) and hypnogram. Here a markedly visible increase in HFD can be observed during wake (W) and REM (R) stages while a significant drop in HFD can be seen during NREM 3 (N3). The large decrease in HFD demonstrates the reduced EEG complexity observed in NREM3's highly synchronous delta band activity. This information can then be used, for example, to score/predict sleep stages. HFD is one of the EEG features that YASA's machine learning sleep scorer uses. Figure taken from https://github.com/raphaelvallat/yasa/blob

Nonlinear characteristics of the EEG signal have been used in the past in sleep science research for sleep stage scoring and normal and pathological condition distinction (see Ma, Shi, Peng & Yang, 2017 review on non-linear sleep EEG analysis) but also in other neuroscience research fields such as anaesthesia, epilepsy, depression, autism, emotion recognition, mental fatigue research (see Bermudez & Garcia-Laencina, 2015 for review on non-linear EEG analysis applications). Nonlinear EEG metrics such as entropy and fractals are thought to provide information on information processing and a measure of functional connectivity (Ismail & Karwowski, 2020; Bermudez & Garcia-Laencina, 2015). For example, it has been demonstrated that EEG complexity increases when one is involved in performing a cognitive task due to an increase in information processing (Ismail, Karwowski, 2020). Thus, it has been demonstrated that adolescents with ADHD exhibit lower EEG complexity when performing an attentional task when compared to controls (Zarafshan et al., 2016).

Finally, as of YASA v.0.4.0 (released in November 2020), automatic sleep scoring was included. YASA's automatic sleep staging algorithm uses a machine learning model, namely Microsoft's LightGBM, which was trained and validated on 3000+ sleep EEG recording data from National Sleep Research Resource (NSRR) website (https://sleepdata.org/). However, YASA's automatic sleep staging algorithm wasn't used in this work as the algorithm requires at least one EMG sensor to score sleep which Hypnodyne ZMax does not have.

1.6.8 Machine learning methodologies used in neuroscience

In the last decade the use of machine learning (ML) algorithms applied in neuroscientific research is evidently steadily growing (Hosseini, Hosseini & Ahi (2020). During wake, machine learning has been applied in a variety of different domains, such as emotion recognition, motor imagery, mental workload, seizure detection and event related potential

tasks (see Craik, He, Contreras-Vidal, 2019 and Hosseini, Hosseini & Ahi, 2020 for reviews). When it comes to sleep science, the vast majority of ML applications have mostly been concentrated in sleep stage recognition, but ML is expanding in other sleep science areas such as in measuring sleep quality (Wang, Zheng, Ma & Lu, 2016), detecting sleep apnoea (Vimala, Ramar & Ettappan, 2019), EEG microarousals (Fernández-Varela, Hernández-Pereira, Álvarez-Estévez & Moret-Bonillo, 2017).

In regard to lucid dream science, the investigation of such extensive number wakefulness and sleep EEG features to predict and customize lucid dream induction techniques to the individual, using machine learning algorithms has not been done before. Typically, when EEG recordings are used in lucid dream studies, the EEG is either only used for manual online and/or offline detection of sleep stages (e.g., Paul, Schädlich & Erlacher, 2014), or to evaluate EEG Fast Fourier Transform (FFT) band power characteristics of lucid dream state epochs vs normal dream epochs (e.g., Voss, Holzmann, Tuin & Hobson, 2009; Voss et al., 2014; Dresler et al., 2012). To date, there has been no single study investigating possible relationship between sleep microstructure features (e.g., sleep spindle, delta, K-Complex) characteristics with dream content stimulus incorporation success and lucid dreaming. These possible relationships are explored in Chapter 5.

In terms of predicting stimulus awakening thresholds (SATs) during REM sleep, (or any sleep stage), ML has not been applied yet and this will be attempted for the first time in Chapter 5. Chapter 2 goes over past research on the presentation of external stimuli during sleep and will lay the foundations for the development of a theoretical and technical framework for the Individualised Auditory Stimulation (IAS) LD induction technique. The central component of the IAS technique is to predict individual SATs using ML algorithms, in order to present

auditory stimuli as loud as possible and to repeat the stimuli as frequently as possible for each individual, without causing any awakenings. The hypothesis that is formed here is that louder and more frequent stimulus repetitions will enhance stimulus incorporation rates into the dream content. Following successful and reliable incorporation, the stimuli can then act as cues to enable the dreamer to realise that they are dreaming. The effect of external stimuli in sleep is discussed further in Chapter 2 and the reasoning behind this hypothesis is explained in more detail in Chapters 2 and 5.

To find optimum ML configurations/pipelines this thesis will utilise TPOT (Fu et al., 2020, June 1), short for Tree-Based Pipeline Optimization Tool. TPOT is an automated machine learning tool, written in Python computing language, which utilises genetic algorithms to optimise ML pipelines (Le, Fu & Moore, 2020; Olson et al., 2016a; Olson et al., 2016b). Genetic algorithms (GAs) are search heuristic algorithms that are based on the theory of natural evolution (Eiben & Smith, 2010). There are five phases in a genetic algorithm: Initial population, fitness function, selection, crossover and mutation. GAs in the context of ML start with an initial population of possible solutions to what is sought to be predicted (i.e., the dependent variable, which in our case is the SAT score). Each solution is characterised by a set of parameters that in evolutionary terms would be called genes. Sets of these 'genes' are joined to form a 'chromosome' (i.e., the solution to predicting the dependent variable; DV). GAs have a fitness function which determines how 'fit' an individual solution is by assigning them a fitness score; in the case of the present study, the percentage of how accurate a ML pipeline is at predicting a variable of interest (i.e., the dependent variable). During crossover, different ML pipelines are 'mated', thus creating offspring (i.e., new ML pipelines that are created from the exchanging of parameters from their parent ML pipelines). The final phase of GAs is called mutation; this is where random low probability mutations occur to parameters of offspring

solutions. Mutation is useful so that premature convergence is avoided (i.e., it prevents the premature production of generations that are not significantly different from the previous generation). To date, TPOT performs a GA process on a total of 32 different feature pre-processing, feature selection, feature construction and ML algorithms in order to find the most optimum ML pipeline for a given dataset (see figure 1.11 and figure 1.12).

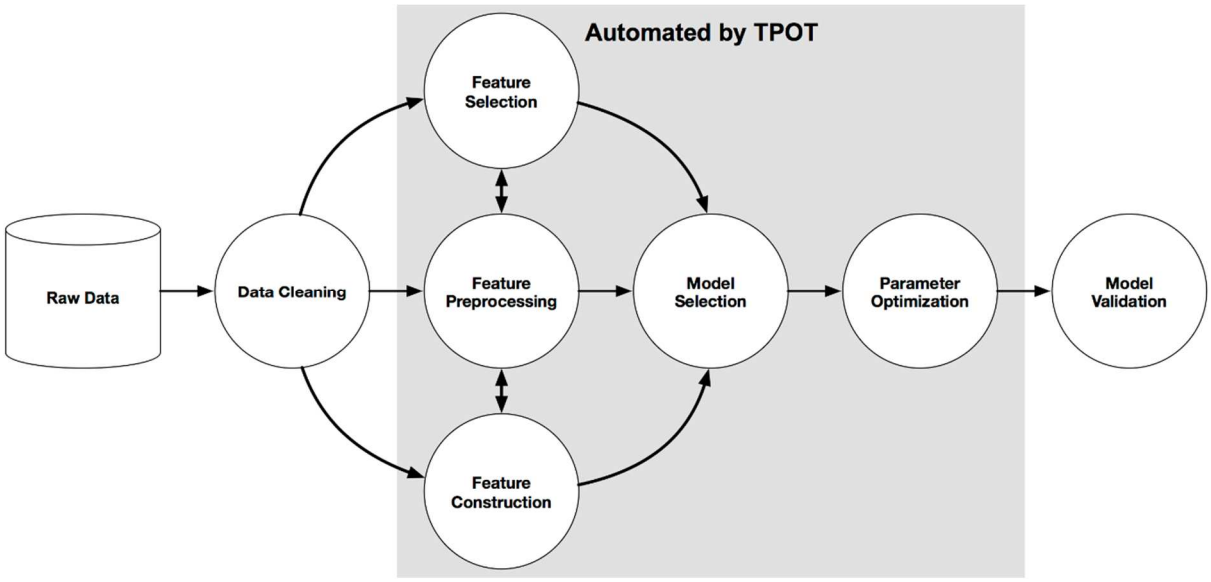

Figure 1.11. An example Machine Learning pipeline, showcasing the automatisation steps taken by TPOT. Taken from TPOT's github page, http://epistasislab.github.io/tpot/

Specifically, TPOT firstly automatises the selection of optimum feature pre-processing, selection and construction algorithms. Following this, it then chooses a ML model and tunes its parameters. In total fourteen pre-processing algorithms are in TPOT, such as 'StandardScaler' (Z-Score standardisation) and 'MinMaxScaler' (Transformation to a given range such as 0-1). TPOT includes five selection algorithms. Feature selection entails choosing the independent variables (IVs) that are relevant to predict the classification or regression task. By performing feature selection, overfitting is reduced as the reduction of redundant data equals to a lesser chance of making decisions based on noise. In addition, by performing feature

selection, the accuracy is improved by reducing misleading data, finally, the training time is reduced as fewer features equal to a reduction in algorithm complexity and run-time. Examples of feature selection algorithms include 'SelectFwe' which selects p-values which correspond to family-wise error rate and 'VarianceThreshold', a feature selector algorithm which removes all low-variance features. Finally, TPOT includes thirteen different ML algorithms, including Logistic Regression, tree-based ML algorithms such as Decision Trees and Random Forest, Naïve Bayes algorithms and various boosting algorithms including eXtreme Gradient Boost (XGBoost; Chen & Guestrin, 2016). Each ML algorithm is then tuned through parameter optimisation processes (figure 1.13).

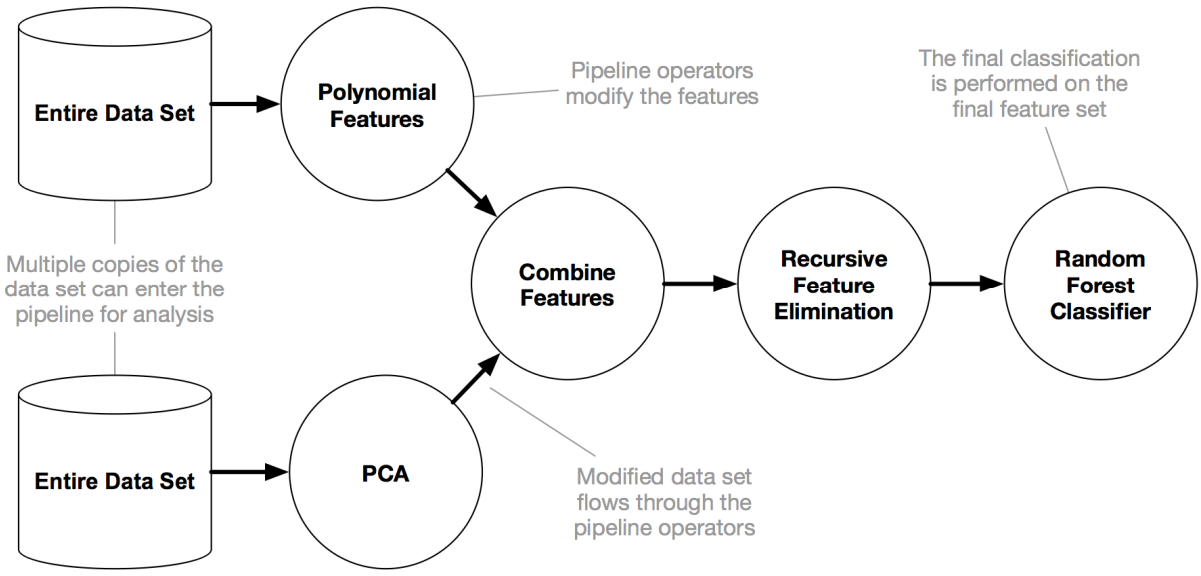

Figure 1.13. An example TPOT pipeline. Taken from TPOT's github page, http://epistasislab.github.io/tpot/

One of the strengths of TPOT is that it can combine ML algorithms together, through a process called 'stacking', first introduced by Wolpert (1992). ML stacking is a method in which the predictions, generated from different types of ML algorithms, are used as inputs to another ML algorithm that gets to decide what the final prediction will be. This decider algorithm is then

trained to optimally combine the model predictions to form a new set of predictions (e.g., figure 1.14).

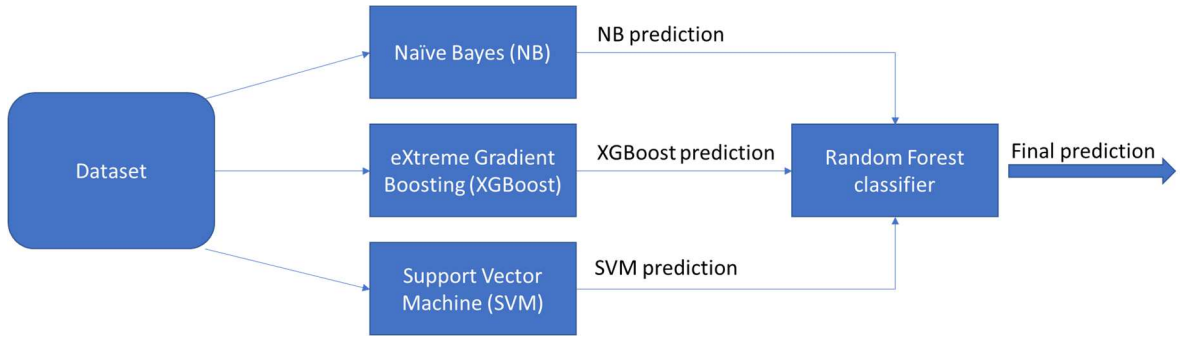

Figure 1.14. Example of ML stacking where the predictions of three ML algorithms (Naïve Bayes, eXtreme Gradient Boosting & Support Vector Machine) are given to a deciding ML algorithm (Random Forest) as additional inputs to form a final prediction.

1.7 Chapter 1 Closing remarks

With the theoretical bases of sleep, sleep staging, polysomnography and thesis' equipment/software covered, the thesis will move on to Chapter 2. Chapter 2 will cover theoretical background of dreams, lucid dreams (LDs) and LD induction techniques, giving a special focus to exploring what external stimulation techniques have done in the past in terms of influencing sleep processes, dreams and inducing LDs. Thus, the theoretical background exploration of Chapter 2 will pave the way for supporting the hypotheses behind the following three study chapters.

CHAPTER 2

Theoretical Background of Dreams, Lucid Dreaming & Lucid Dream induction techniques

We must also inquire what the dream is, and from what cause sleepers sometimes dream, and sometimes do not; or whether the truth is that sleepers always dream but do not always remember (their dream); and if this occurs, what its explanation is.

Aristotle. On Sleep and Sleeplessness. 350 B.C.

2.1 Introduction

Historically, written reports of dreaming and dream interpretation by ancient Sumerians in Mesopotamia date at least far back as 3100 BC. Throughout history, dreams have been associated with prophesying, repressed primal desires, and unconscious mental reflection (Palagrini & Roselnicht, 2011; McNamara & Bulkeley, 2015). Whilst dreaming we experience a consciousness that is often markedly different from that of waking (Hobson, Stickgold & Pace-Schott 1998). Dreaming in and of itself is a hallucination that is internally generated, producing scenarios and situations that are often bizarre and should alert us that what is experienced is not real. However, instead of coming to this realisation, we usually take everything that is happening whilst dreaming as being real. Not only do we lack insight into the fact that we are dreaming, but also other cognitive abilities are markedly lower than when awake. For example, we experience a reduction in attention, memory (particularly autobiographical memory) and we tend to be more emotional and impulsive (Hobson, Stickgold & Pace-Schott 1998).

2.2 Theories of dreaming

The book *The Interpretation of Dreams* (1900) by Sigmund Freud was the first modern psychological study looking into dreams. Freud postulated that dreams were generated by unconscious instincts rooted in our animal nature, which according to Freud, is often immoral and devoid of societal norms. According to Freud, during sleep, our psychological guard is down giving way for our animalistic, unconscious urges to run unhindered (Freud & Dreyfus [1900] 1965; Solms, 2000; 2004). Thus, dreams function to act out and thereby subsequently suppress the need for subconscious and socially inappropriate urges to manifest during wakefulness. Additionally, the latent dream content of the subconscious is modified and then recalled by the dreamer during wakefulness in a way that protects the sleeper from sexual and/or aggressive wishes. Freud postulated that when dream content cannot be modified appropriately it becomes forgotten or it causes awakenings due to its disturbing and emotionally arousing nature. Psychoanalytic theories of dreaming thus place emphasis on dream interpretation techniques, whose aim is to uncover the true content and meaning of dream content.

Since there have been several theories postulating the function of dreams. Zink & Pietrowsky (2015) divide them into Structural/Biological and Evolutionary/Adaptive function theories of dreaming.

2.2.1 Structural/Biological theories

Structural/Biological theories include Random Activation Theory (Hobson & McCarley, 1977), Reverse Learning Theory (Crick & Mitchinson, 1983), the AIM-Model (Hobson, 1992), the Continuity Hypothesis (Domhoff, 1996; 2017), and Protoconsciousness (Hobson, 2009).

2.2.1.1 Random Activation Theory & The AIM Model

Unlike psychoanalytic theories of dreaming, the Random Activation Theory (RAT; Hobson & McCarley, 1977) and its revised form, the activation-input-modulation model (AIM-Model), consider dreaming not to be a goal-directed messenger from the unconscious. According to the Random Activation Theory (Hobson and McCarley 1977), the stimulation of the brain-stem via the ponto-geniculo-occipital (PGO) waves during REM sleep and the subsequent chaotic activation of cortically stored perceptions, memories, and motor sequences is the reason behind the phenomenology of bizarre and often disjointed dream scenarios. The RAT was later revised by Hobson (1990) resulting in the development of the AIM-Model. According to the AIM-Model, every conscious state can be defined as a point in a three-dimensional space. The three-dimensional space points are: the level brain activation (A); the origin of inputs (I) to the activated areas (internal or external); and the mode (M), which refers to the levels of activation of aminergic and cholinergic neuromodulators (Hobson et al., 2000). The fundamental flaw with both the RAT and the AIM-Model is their failure to accommodate for the situation when the organization of dream narratives is well defined (Valli & Revonsuo, 2009). The AIM-Model has also been criticised by Mark Solms, a proponent of psychoanalytic theory, prompting a long-held public disagreement (Hobson, 2000, 2002, 2004, 2005; Hobson, Pace-Schott, & Stickgold, 2000a; Solms, 1997, 2000b, 2004; Solms & Turnbull, 2002). Domhoff (2005) points out that that there are three empirical differences between Hobson and Solms dream theories. Firstly, Solms, as a Freudian psychoanalyst, argues that dreams are meaningful and therefore require interpretation (Solms, 2004), whilst Hobson considers them somewhat meaningless projections of chaotic output caused by the random firing of the pons onto the forebrain (Hobson & McCarley 1977). In regard to where dream generation originates, Solms and Hobson also disagree, as Hobson believes that REM sleep is generated in the pons while Solms surmises that dreaming is generated in the tegmental area of the midbrain, a few

centimetres away from the pons (Hobson, Pace-Schott, & Stickgold, 2000; Solms, 2000). Since the dopaminergic system originates in the ventral tegmental area, Solms considers the dopaminergic system to be highly responsible for dream generation. Additionally, this dopaminergic activity forms/modulates the seeking-reward loop, hence it may also explain the phenomenology of dreams such as the enactment of novelty seeking behaviours whilst dreaming (Solms & Turnbull, 2002). Hobson initially proposed that dreaming was a completely bottom-up phenomenon, with no forebrain input and had downplayed the frequency and quality of NREM dreams (i.e., dreams devoid of cholinergic activity) but has since revised his theory upon seeing evidence showing top-down brain activity (Hobson, Pace-Schott, & Stickgold, 2000b). It should be noted that the Hobson-Solms debate culminated into an Oxford-rules debate at the "Science of Consciousness" in Tucson, Arizona where Solms and Hobson debated on the validity of modern Freudian dream theory, with Solms crowned the winner of the debate (Hobson, Solms, Chalmers, 2006).

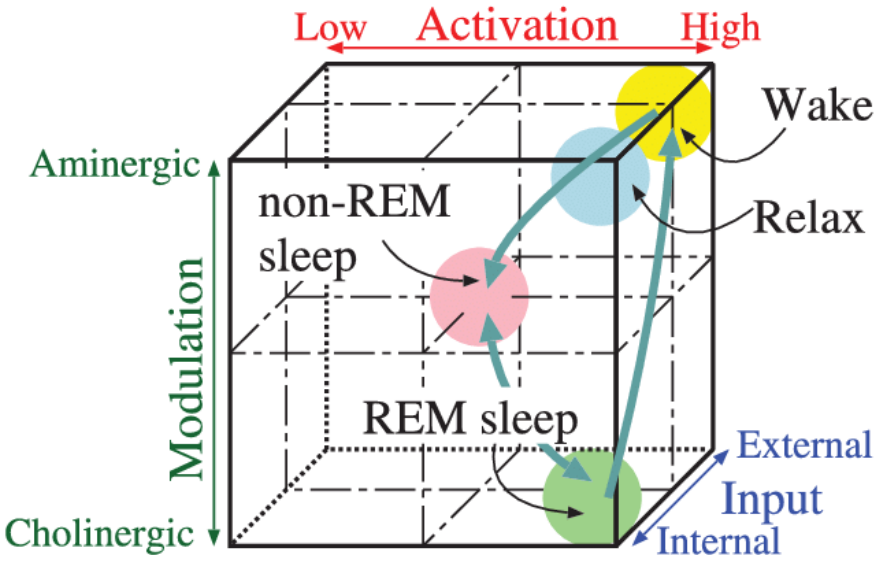

Figure 2.1: Hobson's AIM model. Graph shows non-REM sleep, REM sleep, wake and relaxed state dfferences in the three-axis Activation, Input and Modulation components of the model. Taken from Mikawa, M., Tsujimura, T., & Tanaka, K. (2008).

2.2.1.2 Reverse Learning Theory

The reverse learning theory describes the process of dreaming as akin to an offline "computer mode" during dreaming (Crick & Mitchison, 1983). According to the reverse learning theory, the dream process aims to eliminate unnecessary/unwanted information acquired during wake in order to maintain efficient organisation of memory – a process that may explain why dreams are often quickly forgotten upon awakening. A criticism of reverse-learning theory is that dream narratives are often arranged in a structured way and it is unclear why dreams would have these features when according to reverse-learning theory dreams are supposed to be disposable and/or unwanted information (Zink & Pietrowsky, 2015).

2.2.1.3 Theory of proto-consciousness

According to Allan Hobson's theory of proto-consciousness, both waking and dreaming states cooperate in a continuous phase that is a requisite for proper functioning. Proto-consciousness is a primal state of consciousness that evolves ontologically with brain formation in REM sleep in utero and in early childhood. It is proposed to precede and help establish 'secondary consciousness' – a higher cognitive state that includes self-reflective awareness, abstract thinking, volition and metacognition. Normal dreaming is thus considered a state of proto-consciousness, as it is often devoid of features of secondary consciousness, experienced while being awake. Hobson further argues that REM dreaming is "a state of consciousness that is a fundamental building block of waking consciousness" (Hobson, 2013, p. 162). Further to this, Hobson (1988, p .295) argues that dreams play out endogenous 'instinctual acts', including the so-called four F's of fixed actions (feeding, fighting, fleeing and fornication) with the purpose of improving internal predictive models. Hence, Hobson's proto-consciousness hypothesis suggests that REM sleep dreaming creates a primal inherent virtual reality engine, whose aim

is to minimise free-energy by employing top-down expectations to predict sensory input hence minimising prediction error and improving predictive models in order to prepare us for waking life.

2.2.2 Evolutionary/Adaptive Function dream theories

Evolutionary/Adaptive Function theories include Psychoanalytic Theories (Freud, 1900; Jung, 1974), Costly signalling theories (Valli & Revonsuo, 2009), Sentinel Function theory (Snyder, 1966), Problem Solving & Creativity function theory (Hartmann, 1998), Psychological Healing Theories (Cartwright, 1991; Hartmann, 1995; Kramer, 1993) and Simulation function theories (Revonsuo, 2000).

2.2.2.1 Psychoanalytic theories

As mentioned earlier Freud was the initiator of the psychoanalytic theory of dreaming. Following from Freud, Jung's (1974) psychoanalytic theory of dreaming posits that dreams are subconscious efforts to relay complex meanings by using images and symbols to the dreamer. Jung (1974) proposes that dreams reflect a compensatory function of the subconscious for cognition, behaviour and affect that is not being properly articulated in waking life. However, Jung's compensation view of dreams comes in contrast to the Continuity Hypothesis. (CH; Domhoff, 2011; Hall & Nordby, 1972). The CH posits that dream content is psychologically meaningful projecting current thoughts, concerns and salient experiences (Erdelyi, 2017). Moreover, Jung's psychoanalytic theory of dreaming appears to be refuted by several experiments conducted over the past two centuries which showcase a consistency between dream content and waking cognition (e.g., Calkins, 1893; Weed & Hallam, 1896; Foulkes,

Larson, Swanson, & Rardin, 1969; Foulkes & Rechtschaffen, 1964; Foulkes, Pivik, Steadman, Spear, & Symonds, 1967; Hall & Nordby, 1972; Domhoff, 1999; Patrick & Durndell, 2004).

2.2.2.2 Costly signalling theory

The costly signalling theory (CST; Zahavi, 1975; Smith & Bliege Bird, 2005; Bradbury & Vehrencamp, 1998; Grafen 1990; Maynard-Smith & Harper, 2003), applied as a theory of dream function (McNamara, 2004; McNamara & Szent-Imrey, 2007) is based on the evolutionary theory of sexual selection (Trivers, 1972). CST indicates that certain traits develop as they are indicators of favoured genes. Costly and highly verifiable signals are more likely to be chosen for reproduction by the opposite sex because those signals increase fitness. An example of CST can be made by looking in the animal kingdom such as in the male peacock, whose big, long cumbersome tail makes the male peacock easier to spot by predators. Despite this disadvantage, the bigger and longer the tail of the male peacock is, the more attracted female peacocks become (Fraser, 2012). This is because it showcases to the opposite sex that it can survive predators despite their tail, thus conveying that they have favourable genes such as the ability to run faster. CST as applied to dreaming, notes that REM features influence dream content which in turn affects waking cognition irrespective of successful dream recall in waking. In CST, dreams are seen as an emotional burden, particularly when negative dreams occur, thus, the ability to overcome or remain unaffected by them during wakefulness is thought to showcase fit genes to others (Valli & Revonsuo, 2009). Issues with CST, as applied in dreaming, include the inability to explain how REM sleep and dreams influence waking and how the effects costly features of REM and dreaming can be observed and evaluated directly or indirectly by others (Zink & Pietrowsky, 2015)

2.2.2.3 Sentinel function theory

According to the sentinel function theory (SFT; Snyder, 1966), the increased level of brain activity in REM (when compared to other sleep stages) is optimum for responding to possible external threats and that dreams aid in the preparation and prediction of 'fight or flight' responses (Valli & Revonsuo, 2009).

In addition, evidence put forth for the predictive and preparatory function of REM sleep and dreaming of SFT include the capability of the sleeping brain to process external stimuli (Blume, del Giudice, Wislowska, Heib & Schabus, 2018) and that stimuli presented during REM sleep tend to become incorporated into the dream content (Solomonova & Carr; 2019), although usually in an indirect way (Schredl, 1999). More in-depth discussion on external stimulus processing during sleep and how this can be used to trigger LDs is discussed below.

SFT also proposes that animals living in groups share the task of protecting the group by always having a subset of the group being vigilant to threats whilst other group members sleep (Snyder, 1966). An actigraphy watch study on the hunter-gatherer Hudza tribe in Tanzania by Samson, Crittenden, Mabulla, Mabulla, & Nunn (2017) has provided some evidence to support this aspect of SFT in humans. The researchers were able to track activity and sleep patterns of multiple members of Hudza tribe and found that there were only 18 minutes within the 24-hour cycle that all tribe members were asleep and besides that time, 40% of the tribe was awake at any given point. The numbers are kept this way in part due to differences in circadian rhythms between younger and older generations – younger members stay up later at night and sleep longer during the morning while elders have the opposite pattern.

2.2.2.4 Problem Solving & Creativity function theory

> "*I turned the chair to face the fireplace and slipped into a languorous state. Again, atoms fluttered before my eyes. Smaller groups stayed mostly in the background this time. My mind's eye, sharpened by repeated visions of this sort, now distinguished larger figures in manifold shapes. Long rows, frequently linked more densely; everything in motion, winding and turning like snakes. And lo, what was that? One of the snakes grabbed its own tail and the image whirled mockingly before my eyes. I came to my senses as though struck by lightning; this time, too, I spent the rest of the night working out the results of my hypothesis*."
>
> Friedrich Kekulé, on his discovery of the molecular structure of benzene, (Translated in Rothenburg, 1998).

A common phrase used when one needs to mull over a problem and figure out a solution or make a decision, is to 'sleep on it' (Merriam-Webster, n.d). Hartmann (1998) proposed that the synaptic formation and pruning that occurs whilst in REM and the phenomenology of dreaming had two evolutionary functions. The first function of dreaming was to aid in problem-solving through a psychological healing mechanism, in order to help with the almost-everyday traumatic waking experiences accrued by the harsh reality of living in the ancient world, fraught with violence, animal predators, diseases and in general, being very much at the mercy of the natural environment. The second function of dreams was to provide problem-solving solutions through creative thinking made possible through the broader associations created whilst dreaming. As such, dreaming is considered to have helped our ancestors integrate

waking knowledge in beneficially novel ways, further indicating that the earliest form of human creativity may have been dreaming (Barrett & McNamara, 2007).

Past research has shown that indeed, sleep helps improve problem solving (Linde & Bergströme, 1999; Monanghan et al., 2015; Brodt, Pöhlchen, Täumer, Gais, Schönauer, 2018; Sanders, Osburn, Paller and Beeman, 2019) especially as problem complexity increases (Na Sio, Monaghan, Ormerod, 2013). More specifically relating to dreaming, Schredl (1995) demonstrated that higher visual and verbal creative skills are correlated with higher dream recall frequency (DRF) and Cai, Mednick, Harrison, Kanady & Mednick (2009) showed that it is REM sleep specifically that is involved in improving creative problem solving and not NREM sleep, showcasing that REM sleep is crucial in the formation of associative networks during sleep. Finally, Page & Kwiatkowski (2003) demonstrated that dreaming serves a functional role in creative processes, particularly for those who have a product-oriented creative interest (i.e., to produce art, music, crafts, writing, theatre) compared to those with a purely creative interest (e.g. games, history, reading, etc).

2.2.2.5 Psychological Healing Theories

Psychological Healing Theories (PHT) state that dreaming essentially acts as "form of overnight therapy" (p.443, Walker, 2009), in order to help the organism maintain psychological balance by facilitating emotional wellbeing against daily stressors (Cartwright, 1991; Hartmann, 1995; Kramer, 1993; Garfield, 1991). Evidence to support PHT comes from various studies, which showcase that REM sleep is selectively involved in emotional memory processing (e.g., Wagner, Gais & Born, 2001; Wagner et al., 2006; Wagner, Kashyap, Diekelmann & Born, 2007; Nishida, Pearsall, Buckner, Walker, 2009; Walker & van der

Buckner, 2009; van der Helm & Walker, 2010). It is postulated that during REM sleep, negative emotional traces are integrated into broader networks in a way that reduces their emotional load (Scarpelli, Bartolacci, D'Atri, Gorgoni & De Gennaro, 2019; Zink & Pietrowsky, 2015). Specifically, the encoded emotional wake experiences that are modulated by aminergic activity are reactivated in the aminergic-devoid, cholinergic-dominating state of REM sleep, thus allowing for the depotentiation of their affective tone (Walker & van der Helm, 2009). At the same time, the strengthening of cortico-cortical connections during REM allows for the integration and assimilation of waking emotional experiences into previous autobiographical experiences, possibly giving rise to the experience of dreaming (Nishida et al., 2009; Walker & van der Helm, 2009).

The connection between REM sleep and emotional memory consolidation is showcased by the fact that REM sleep alterations, including the appearance of re-current and frequent dreams and nightmares often co-exist with a variety mood disturbance disorders and psychiatric conditions (Benca et al., 1992, 1997; Walker and van der Helm, 2009; Cartwright et al., 2003; Modell et al., 2005; Agargun et al., 2007; Schredl et al., 2009; Sjöström et al., 2009; Marinova et al., 2014; Nakajima et al., 2014). Specifically, it is thought that when the emotional memory integration processes during REM fail, then posttraumatic dreams/nightmares remain for longer (Nishida et al., 2009). In addition, Nishida et al (2009) demonstrated that emotional memory consolidation is positively correlated with the amount of REM sleep and that emotional memory consolidation is coordinated by right prefrontal theta EEG band activity (Nishida et al., 2009).

2.2.2.6 Simulation function theories

Simulation function theories are founded upon the hypothesis that dreams are intended to simulate waking life in order to safely rehearse waking life situations and interactions. Simulation function theories posit that dreams have a 'play function', a 'social simulation function' and a 'threat simulation function' (Zink & Pietrowsky, 2015). Thus, a connection is made between dreams and play behaviour that is experienced in mammals (Bulkely, 2004;2019; Humphrey, 2000). An example of this can be seen in domestic pets, such as in cats, where they can often be seen 'play fighting' with each other. The function of these play behaviours is thought to provide an evolutionary adaptive role by improving responses to threatening situations through rehearsing hunting behaviours, hostile interactions and learning how to avoid predators (Valli & Revonsuo, 2009). According to simulation function theories, such as the Threat Simulation function (TST; Revonsuo, 2000), dreams, serve a similar function to play behaviours. Thus, the simulation of possible situational and social scenarios and rehearsal of responses to them whilst dreaming plays an evolutionary adaptive role as it improves the likelihood of survival and reproductive success (Barrett & McNamara, 2007; Valli & Revonsuo, 2009). Supporting evidence for TST come from the fact that dream themes which include negative emotions, aggression and being chased are quite frequent dream scenarios (Domhoff & Schneider, 2008)

2.3 The neurobiology and phenomenology of dreams

The phenomenal characteristics of dreaming have been correlated with specific neuronal activation patterns (figure 2.2).

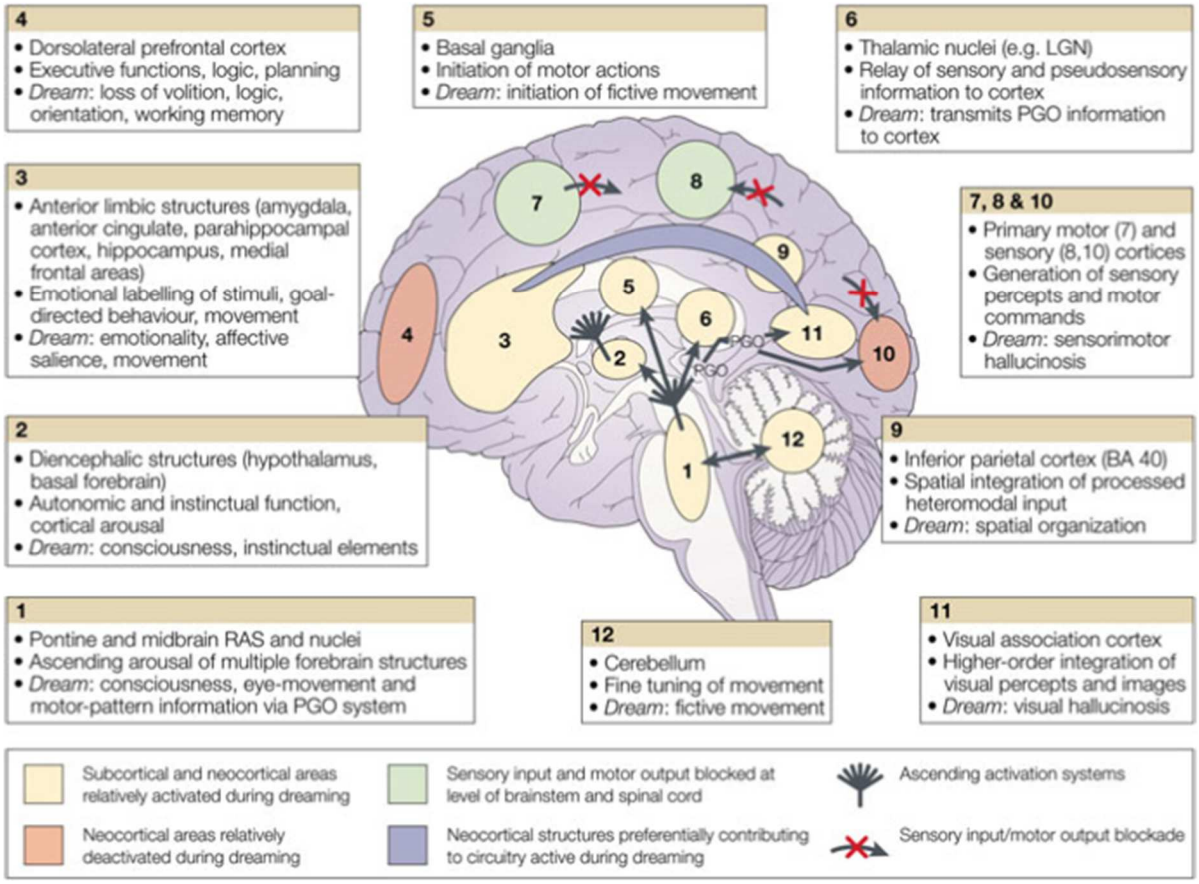

Figure 2.2. The function of various brain areas during wake and normal dreaming such as ascending arousal systems (1,2), subcortical and cortical limbic and paralimbic structures (3); dorsolateral prefrontal executive association cortex (4), motor initiation and control centers (5), thalamocortical relay centers and thalamic subcortical circuitry (6), primary motor cortex (7), primary sensory cortex (8); inferior parietal lobe (9), primary visual cortex (10), visual association cortex (11); cerebellum (12) (taken from Tranquillo, 2014).

The deactivation of frontotemporal regions and activation of occipito-parietal regions is thought to lead the dreamer to experience primary consciousness (Edelman, 2004): a weak cognitive state with defective insight, orientation and memory that is perceptually rich and filled with powerful emotions. Specifically, in accordance to the visuomotor hallucinations of dreaming, higher visual and motor areas show strong metabolic activity (Maquet et al., 1996; Braun et al., 1998). Emotional processing areas such as the amygdala, medial prefrontal cortex and anterior cingulate cortex, show increased activity during REM (Maquet et al., 1996; Braun

et al., 1998; Vandekerckhove & Cluydts, 2010), thought to reflect the intense emotions experienced in dreams (Hobson et al., 2000). Additional emotional processing areas, such as the pontine tegmentum, thalamus, basal forebrain, hippocampus and parietal operculum, also show increased neuronal activity during REM, supporting the putative role of REM sleep in emotional memory consolidation (Vandekerckhove & Cluydts, 2010; Stickgold et al., 2001; Walker & Stickgold, 2006).

Conversely, the dorsolateral prefrontal cortex, orbitofrontal cortex and specific parietal areas such as the supramarginal cortex, precuneus, posterior cingulate gyrus and inferior parietal cortex, show low metabolic rates during REM sleep (Maquet et al., 1996; Braun et al., 1998; Vandekerckhove & Cluydts, 2010). The deactivation of these areas is thought to impair executive and attentional functions such as metacognitive monitoring, critical thinking, as well as impair volitional capability (Desseilles et al., 2011; Hobson et al., 2000; Dresler et al., 2012). As mentioned in Chapter 1, dreams had been traditionally associated with the wake-like, EEG high-frequency REM stage of sleep and to be absent in the NREM stage. However, contrary to earlier findings, dream reports have been attained in NREM stage of sleep, in a laboratory setting, at up to 70% of the time (Stickgold et al., 2001), which although less than in REM (Dement & Kleitman 1957a; 1957b; Hobson, 1988b), demonstrate that NREM dream recollection is significantly higher than what was originally thought. Later studies by Siclari et al (2017) and Siclari, Bernardi, Cataldi & Tononi (2018) have found that reduced delta and increased “fast” spindle activity in the posterior cortical predicts reports of dream experience in NREM and REM sleep. Moreover, Siclari et al (2017) were then able to predict with 87% accuracy when participants awakening from NREM sleep would report dreaming or not.

Phenomenological differences between REM and NREM dreams have been uncovered through serial awaking paradigms and collection of dream reports. Dream reports collected in REM are

usually longer, more bizarre, more perceptually vivid, more emotionally charged and more animated, while NREM dream reports exhibit more thought-like mentation and representation of current concerns *(*Foulkes et al., 1988; Nielsen et al., 1991; Merritt et al., 1994; Hobson et al., 2000; Kahn et al., 2002; Hobson, Pace-Schott, & Stickgold, 2000; Speth, Harley & Speth, 2016). Furthermore, graph analysis of structural differences between REM and NREM dream reports by Martin et al. (2020), showed that REM dreams reports are far more complex and full of connected information than NREM dreams.

2.4 Defining Lucid Dreaming

…οὕτω καὶ ἐν τοῖς ὕπνοις, ἐὰν μὲν αἰσθάνηται ὅτι καθεύδει, καὶ τοῦ πάθους ἐν ᾧ ἡ αἴσθησις τοῦ ὑπνωτικοῦ, φαίνεται μέν, λέγει δέ τι ἐν αὐτῷ ὅτι φαίνεται μὲν Κορίσκος, οὐκ ἔστι δὲ ὁ Κορίσκος (πολλάκις γὰρ καθεύδοντος λέγει τι ἐν τῇ ψυχῇ ὅτι ἐνύπνιον τὸ φαινόμενον)· ἐὰν δὲ λανθάνῃ ὅτι καθεύδει, οὐδὲν ἀντιφήσει τῇ φαντασίᾳ.

...if the sleeper perceives that he is asleep, and is conscious of the sleeping state during which the perception comes before his mind, it presents itself still, but something within him speaks to this effect: 'the image of Koriskos presents itself, but the real Koriskos is not present' (for often, when one is asleep, there is something in consciousness which declares that what then presents itself is but a dream) If, however, he is not aware of being asleep, there is nothing which will contradict the testimony of the bare presentation.

Aristotle (c.350 BC), On Dreams, Chapter 3, translated by J. I. Beare (1906).

The Dutch psychiatrist van Eeden (1913) was the first to originate the term “lucid dreaming”. It refers to the phenomenon whereby a dreamer is aware that he or she is dreaming while dreaming (e.g, LaBerge, 1987; Spoormaker & van den Bout, 2006). Broader definitions of

lucid dreaming include not just having increased reflective insight, but also of having full intellectual clarity, including the availability of autobiographic memory sources and the ability to actively control the dream (Tart, 1988; Metzinger, 2003; Windt & Metzinger,2007).

In order to quantifiably assess dream lucidity, the Lucidity and Consciousness in Dreams Scale (LuCiD), was developed by Voss et al (2013). The LuCiD scale is an analytically derived and validated eight factor scale, stemming from over 300 non-lucid and lucid dreams and constructed by an "interdisciplinary team of philosophers, psychiatrists and psychologists" (Voss & Hobson, 2015, p 10). The eight factors were INSIGHT, REALISM, CONTROL, MEMORY, THOUGHT, POSITIVE EMOTION, NEGATIVE EMOTION and DISSOCIATION (Voss et al., 2013). Defining the factors, INSIGHT, the leading factor in dream consciousness, is described as the knowledge that one is dreaming; that what is experienced is not real. The REALISM factor is defined as the sense that the similarity between emotions, thoughts and events experienced in the dream correspond to that of wakefulness. CONTROL is defined as the ability to influence the dream plot. MEMORY is described as the ability to access waking memory. THOUGHT is demarcated as the capability to think logically about other dream characters and about the self. POSITIVE/NEGATIVE EMOTION pertains to the positive and negative emotions experienced in the dream and DISSOCIATION is defined as the ability to take a third-person perspective. Using the LuCiD scale, a clear distinction is made between lucid and non-lucid dreams. Non-lucid dreams score low on most factors, especially on INSIGHT, CONTROL and DISSOCIATION. Surprisingly, REALISM is not distinguishable between lucid and non-lucid dreams, meaning lucid dreams feel as subjectively realistic as non-lucid dreams. On the other hand, the leading factors in lucid dreams are INSIGHT, CONTROL and DISSOCIATION (Voss et al., 2013).

2.5 Lucid Dream Frequency and Prevalence

Lucid dreaming is thought to be a rare occurring phenomenon of REM sleep. Various surveys have tried to estimate the lucid dream occurrence and frequency in the general population (Stepansky et al., 1998) and in student samples (e.g., Stepansky et al., 1998; Schredl & Erlacher, 2004; Schredl & Erlacher, 2011; Gackenbach, 1991; Blackmore, 1982; Palmer, 1979). A recent quality effect meta-analysis of lucid dream prevalence and frequency studies by Saunders et al. (2016) has shown that the proportion of individuals who have experienced at least one lucid dream in their lifetime is 55% and that 23% report experiencing lucid dreams once a month or more. The authors postulate that the high percentage of the population reporting that they experienced at least one lucid dream in their lifetime, "suggests the capacity for lucid dreaming is widespread" (Saunders et al., 2016, p. 210). Similar results are found world-wide, across Latin America, USA, Europe and Asia (Ribeiro, Gounden & Quaglino, 2016).

Dream Recall Frequency (DRF) has been found to be highly positively correlated with lucid dream frequency (Belicki, Hunt, & Belicki, 1978; Blackmore, 1982; Hearne, 1978; Watson, 2001; Wolpin et al., 1992); something that should not come as a surprise as the more dreams someone can successfully recall, the more likely it is to recall dreams that were lucid. Perhaps more interestingly, DRF may be correlated with possible neurobiological differences in brain activation patterns. In a recent study by Eichenlaub et al. (2014) of high DRF vs low DRF participants, it was found that high DRF participants exhibited higher temporo-parietal junction (TPJ) and medial-Prefrontal Cortex (mPFC) activations during REM sleep. The authors postulate that increased activity in the TPJ and mPFC might promote the mental imagery and/or memory encoding of dreams. In addition, an fMRI study by Vallat, Eichenlaub & Ruby (2018) showcased that higher DRF is associated increased mPFC white-matter density. Further

evidence to the importance that the frontal lobe plays, in the experience and/or the ability to recall dreaming experiences come from Solms (1997;2000) who found that mPFC lesions lead to partial or total cessation of dream recall. Further evidence as to the crucial part that mPFC plays in dream generation and recall come from Marzano et al. (2011) and Scarpelli et al. (2015) who found that frontal theta bandpower is increased in successful dream recall. Nielsen et al (2016) investigated the role of sleep spindles in DRF and found that all their dream recall measures (N2 sleep spindle density, REM dream word count, retrospective DRF, bad dreams and nightmares) were positively correlated with the density of fast spindles of N2 sleep. Slow spindle density displayed opposite correlations, however, partialing out slow spindles attenuated, but did not eliminate, the fast spindle correlations. The authors postulate that dreaming and spindles may reflect a shared trait or mechanism of sleep-dependent memory consolidation which occurs through memory replay (Nielsen et al., 2016). For example, it has been shown that persons with high DRF perform better in mirror-tracing task when compared to those who exhibit low DRF (Dumel, Marquis, Blanchette-Carriere, Paquette & Nielsen, 2015). Furthermore, brain areas implicated with spindle production are also implicated in dream generation/recall (Schabus et al., 2007; Hobson, Stickgold & Pace-Schott, 1998). Finally, in auto-activation deficit, a neuropsychological syndrome caused by bilateral damage to the basal ganglia and is characterised by apathy, loss of self-driven behaviour, mental emptiness (absence of any self-reported thoughts) both dream recall measures and spindles are impacted (Leu-Semenescu et al., 2013). Specifically, patients with auto-activation deficit have low DRF and report a reduction in a variety of other dream metrics (e.g., duration and dream content detail, dream bizarreness), and also exhibit a reduction in spindle density (Leu-Semenescu et al., 2013), despite the thalamus being intact (the area responsible for spindle generation).

Research on other individual personality differences has demonstrated that lucid dream occurrence appears to be correlated with age (Hess, Schredl and Goritz, 2016; Voss et al., 2012; Stumbrys et al., 2014), and with personality traits such as: Openness To Experiences of the Big Five personality dimensions (e.g., Hess, Schredl and Goritz, 2016); creativity (e.g Blagrove & Hartnell, 2000; Zink & Pietrowksy, 2013); hypnotic suggestibility (Hoyt, Kihlstrom & Nadon, 1992), mindfulness (Stumbrys, Erlacher, & Malinowski, 2015; Stumbrys & Erlacher, 2017); meditation (Reed, 1978; Sparrow, Thurston & Carslon, 2013); thin boundaries (Galvin, 1990; Hicks, Bautista, & Hicks, 1999; Schredl & Erlacher, 2004); internal Locus Of Control (iLOC) and Need for Cognition (NFC; Blagrove & Hartnell, 2000). Specifically, as opposed to people with "thick boundaries" who are characterised as being rigid and guarded, those who exhibit "thin boundaries" between their mental processes, not only are more open-minded, sensitive, allow themselves to be vulnerable and are more creative, but they also experience higher LDF (Blagrove & Hartnell, 2000). People who score high on iLOC (Levenson, 1981) not only have belief in their own control over events and outcomes as opposed to attributing significance to powerful others or in chance, but were also found to have higher LDF (Blagrove & Hartnell, 2000). NFC is a term that refers to the capacity and proclivity for engaging in and enjoying cognitively demanding activities and has been found to be positively correlated with LDF. Both iLOC and NFC are thought to be related to LDF as persons who score high in these exhibit higher cognitive complexity, flexibility and metacognitive ability during wake that transfers to dreaming consciousness and cognition.

Moreover, LDF seems to decline with age (Schredl et al., 2014; Schredl & Erlacher, 2011; Schredl & Goritz, 2015), an effect that is attributed to cognitive decline and age-related changes in PFC activation (Maillet & Rajah, 2013). In addition, it is postulated that an increase in video gaming and in meditative practises in younger generations is also driving this effect as

meditation practice and video gaming frequency has been correlated with LDF (Gackenbach, 2006; Reed, 1978; Sparrow, Thurston & Carslon, 2013). As such, video gaming has been suggested as a means to increasing dream control and mindfulness (Gackenbach & Bown, 2011; Gackenbach et al., 2015).

With regard to personality correlates, the OCEAN personality model factor 'Openness to Experience' has been found to be positively correlated with LDF (e.g., Hess, Schredl and Goritz, 2016), People who score high on this factor tend to be adventurous, open-minded, intellectually curious, creative and imaginative (McCrae, 1994; Ostendorf & Angleitner, 2004), hence other LDF significant personality correlates such as creativity, thin boundaries, NFC and hypnotic suggestibility can be considered as subdimensions of this OCEAN factor (Hess, Schredl and Goritz, 2016).

Regarding Mindfulness, Stumbrys & Erlacher (2017) found that it not only increases lucid dream frequency, but also increases the ability to control lucid dreams. Their results suggest that controlling the dream content can be increased through dispositional mindfulness. Studies showcasing a positive relationship between meditation (Stumbrys, Erlacher, & Malinowski, 2015; Stumbrys and Erlacher, 2017; Reed, 1978; Sparrow, Thurston & Carslon, 2013) further suggest that there exists a transferable attentional control and metacognition ability between waking and dreaming (Malinowski, 2013; Stumbrys et al., 2015).

2.6 Psychophysiological measures employed for the study of lucid dreams

Psychophysiological measures used in polysomnography, such as electroencephalography (EEG), functional magnetic resonance imaging (fMRI), electromyography (EMG), electrooculography (EOG), electrocardiogram (ECG) and pressure transducers, have been used

in the study of lucid dreams, with several studies using more than one of these methods in conjunction. Initially it was theorised that lucid dreaming reflected brief waking periods in the night (e.g., Hartmann, 1975) but since then this idea has been debunked by studies from Hearne (1978) and LaBerge (1980) who, via the use of techniques such as eye movement signalling, demonstrated that lucid dreaming occurs during REM sleep. Eye movements during REM sleep correspond to where the dreamer is looking whilst dreaming (e.g Brandt & Stark, 1997) thus, in lucid dreaming research, using EOG, predetermined eye movement patterns, set and learned prior to sleeping, have been used to signal dream lucidity (e.g., Hearne, 1978; LaBerge, 1980; LaBerge et al., 1981; LaBerge, 1990), as well as to signal the beginning and end of completed dream tasks (e.g., Erlacher et al., 2014).

Other psychophysiological measures such as EMG (LaBerge et al, 1981; Fenwick et al., 1984; LaBerge et al, 1983), ECG (Erlacher & Schredl, 2008) and pressure transducers (LaBerge & Dement, 1982b), have been used for lucid dreamers to send signals back to the experimenter as well as to validate the scientific study of lucid dreams. Using EMG, experimenters were also able to correlate EMG activity produced by subjective (fictive) experiences of left/right fist clenching (LaBerge et al, 1981; Fenwick et al., 1984) and of orgasm (LaBerge et al., 1983), in lucid dreams. Cardiovascular changes have been observed, using ECG, after the subjective experience of performing physical activity (Erlacher & Schredl, 2008). Using pressure transducers subjective breathing patterns performed in dreams have been correlated with actual breathing patterns (LaBerge & Dement, 1982). More recently, in Konkoly et al (2021), whilst dreaming, a portion of lucid dreamers (47%) were able to perceive and respond to simple mathematical questions using eye movements and to yes/no questions by contracting zygomatic or corrugator facial muscles, for a yes or no response.

Neuroimaging studies on lucid dreamers by Voss et al (2009) and Dresler et al (2012) using EEG and fMRI/EEG respectively, have shown REM-like delta and theta activity and higher-than-REM gamma activity, peaking at 40 Hz, in the frontal and frontotemporal regions of the brain whilst experiencing lucid dreams.

The increased frontotemporal activation and the higher-than-REM gamma activity experienced in the frontotemporal regions of the brain is thought to underlie secondary consciousness in lucid dreamers; a higher cognitive state than primary consciousness, which includes features such as self-reflective awareness, insight, judgement, abstract thinking and volition (Edelman, 1992). It is thus hypothesised that dream lucidity is a hybrid state, containing both waking and dreaming consciousness elements (Voss & Hobson, 2015).

2.7 Theories on lucid dreaming and compatibility with dreaming theories

Based on the multitude of studies that have established that LD is a real phenomenon with markedly different brain activity during sleep, researchers have attempted to account for LD in their dreaming models (e.g., Hobson's AIM model) whilst others, such as Zink & Pietrowsky (2015) have investigated how compatible the various dream theories are with LD, Voss & Voss (2014) developed the Space of Consciousness (SoC) model, based on the supposition that "consciousness is a dynamical process unfolding in a phenomenal state-space continuum occupied by states of arousal such as waking, sleep and coma" (Voss & Hobson, 2015, p.10). SoC defines consciousness as a three-dimensional space, with different states varying as a function of sensing, judging and motor control. In this model, lucid dreaming sits just after

REM sleep, closer to waking, in accordance with the neurobiological and phenomenal profiles it exhibits (figure 2.3).

In Hobson's AIM model, the hybrid REM-wake state of lucid dreaming can be explained as a dissociation along the A-axis of the model (figure 2.4). Hobson's AIM model is thus compatible with LD, contrary to his earlier random activation theory model (Hobson & McCarley, 1977) which would not be able to explain lucidity (Zink & Pietrowsky, 2015).

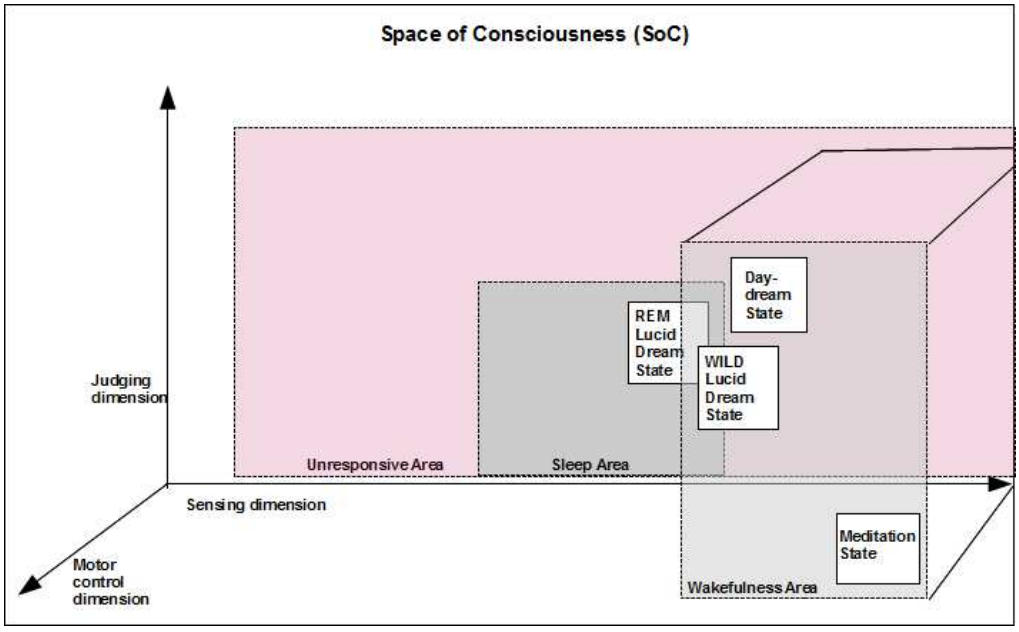

Figure 2.3 The 3-Dimensional Space of Consciousness model demonstrating various states of consciousness in the three dimensions of motor control, sensing and judging (Taken from Voss & Voss, 2014)

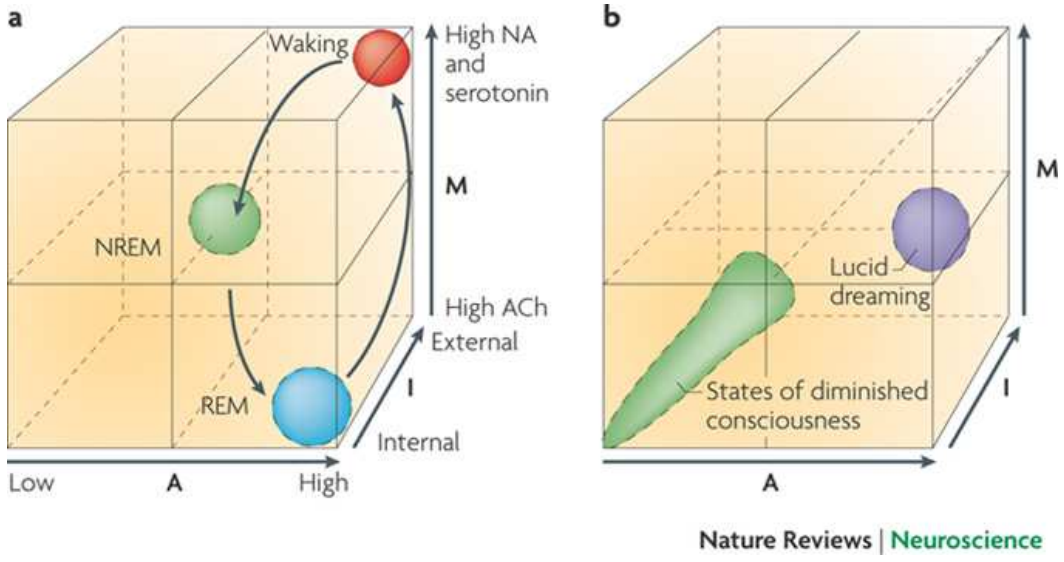

Figure 2.4 The AIM model of varying states of Consciousness. Left figure (a) shows differences between waking, NREM and REM along the activation (A), input (I) and modulation (M) axis of the AIM model. Right figure (b) shows AIM differences between states of diminished consciousness and lucid dreaming. Placement of the lucid scale along the AIM model axis in figure b should not be compared to figure a. If REM and the lucid dreaming state were placed in the same figure, lucid dreaming would be to the right of REM as whilst lucid dreaming there is an increase in frontotemporal activation, when compared to REM. Figure taken from Gott, Liley & Hobson, 2017.

In regard to the Reverse Learning Theory, it is not clear how LD fits as LD likely produces the opposite effect of memory strength equalisation (Zink & Pietrowsky, 2015). For example, studies where lucid dreamers are asked to practise motor skills in their dreams (Stumbrys, Erlacher, & Schredl, 2016; Erlacher & Schredl, 2010; Erlacher & Chapin, 2010; Erlacher, 2005; LaBerge & Rheingold, 1990; Tholey, 1991), showcase a significant improvement in performance, compared to lucid dreamers who didn't practise in their dream (see more about motor skill practise in dreams below).

The Continuity Hypothesis, in the context of LD, explains that contemplative consciousness exists in a continuum in all dreams and is not a discrete phenomenon (La Berge and DeGracia, 2000). In addition, there seems to be a relative continuity between waking cognition/metacognition with LD (Zink & Pietrowsky, 2015). This is firstly evidenced by the aforementioned findings from LD motor skill practice studies which show transferable motor skill improvement from LD to wakefulness (Erlacher & Schredl, 2010). Secondly, the continuity between wakefulness and the LD state can be seen by the effectiveness of cognitive LD induction techniques, which often ask participants to form habits whilst awake that are often transferred to dreaming and thereby help to induce LD (Stumbrys et al., 2012 for review, but also see section 2.8 'Triggering dream lucidity'). Thirdly, studies reporting that meditation frequency (e.g., Reed, 1978; Sparrow, Thurston & Carslon, 2013), practise of mindfulness meditation (e.g., Stumbrys & Erlacher, 2017) and ability to perform well on the Stroop task (Blagrove, Bell and Wilkinson, 2010), (which measures selective attention capacity and skill,

as well as processing speed) are linked with higher LDF, suggest that there exists cognitive and metacognitive ability continuity between wakefulness and dreams (Zink and Petrowsky, 2015).

2.8 Triggering dream lucidity

Lucid dreaming is thought to be a skill that can be trained to occur more frequently. Several lucid dreaming techniques, ranging from cognitive approaches and external stimuli stimulation to drug applications, have been developed to increase the frequency of lucid dreams, with varying degrees of success (see Stumbrys et al., 2012 for a review).

2.8.1 Cognitive techniques

Common and highly successful lucid dream induction techniques are Mnemonic Induction of Lucid Dreams (MILD), Wake-Back-to-Bed (WBTB), Reflection or Reality Testing, Intention, Autosuggestion, and Tholey's Combined Technique (Stubrys et al., 2012).

Specifically, the MILD technique entails rehearsing a dream prior to falling asleep and visualising becoming lucid while focusing on the intention to remember that one is dreaming (LaBerge, 1980b). Barring two field studies by Levitan (1989; 1990), an LD induction technique review paper by Stumbrys et al. (2012) showcases that MILD is always paired with other LD induction techniques, most commonly with the Wake-Back-To-Bed (WBTB) method.

In the WBTB method, it is suggested that an alarm is scheduled to wake an individual some time before natural wake time (usually 2-3 hours) and once awoken, the individual has to stay

awake for a certain period of time (e.g., 30 minutes), while doing lucid dream induction techniques such as MILD. It has been suggested that the effectiveness of WBTB is due to the rising cortical activation caused by the brief awakening, which can activate areas related to LD (Smith & Blagrove, 2015). Further evidence towards this suggestion comes from Smith & Blagrove (2015) who found a significant positive relation between lucid dream frequency and awakenings per night, number of uses of alarm clock snooze function per morning and dream recall frequency. Further evidence for this supposition come from Konoly & Burke (2019) who found that sleep disruption is associated with LDF. It has also been suggested that late REM sleep duration (e.g., through the REM rebound effect) increases the likelihood of LD (Dijk & Czeisler, 1994; LaBerge et al., 1986). Evidence towards this view comes from positive relationship between narcoleptics and LDF (Rak, Beitinger, Steiger, Schredl, & Dresler, 2015), who experience minimal REM latency due to their condition (Dodet, Chavez, Leu-Semenescu, Golmard, & Arnulf, 2015). Moreover, late morning dreams exhibit a higher DRF which is tied to higher LDF (Carr & Solomonova, 2019).

2.8.1.1 WILD techniques

WILDs, short for Wake Induced Lucid Dreams, are lucid dreams in which one is transported directly from being awake into a lucid dream. When practising WILD techniques, one is instructed to try remaining conscious by performing certain cognitive tasks while allowing their body to fall asleep. Since WILDs require a delicate balance of relaxation and unbroken conscious awareness during the transition into REM, they are considered more difficult to achieve, and WILD attempts carry an increased risk of experiencing sleep paralysis, which can be unpleasant (Cheyne, 2003; Sharpless & Barber, 2011). WILD techniques include the hypnagogic imagery technique, the one body technique, the counting yourself to sleep

technique, Tholey's Image-Ego, Tholey's Combined Technique and the Senses Initiated Lucid Dream technique.

2.8.1.2 Hypnagogic Imagery Technique (HIT)

Specifically, the Hypnagogic Imagery Technique (HIT) entails focusing the attention on observing passively the hypnagogic images that start appearing while the person enters sleep stages (Tholey, 1983). If one is successful with this technique, the hypnagogic images start becoming more complex as sleep progresses until they find themselves in a fully-fledged dream. Research into hypnagogic imagery has shown that it indeed becomes more complex as sleep progresses, from simple static 2D monochromatic geometric patterns to moving patterns to complex animated 3D colourful images (Nielsen, 1995) while one progresses through the first five out of the nine Hori stages of sleep (described in Chapter 1; Hayashi, Katoh & Hori, 1999). In addition to visual hallucinatory changes, auditory, tactile, gustatory, olfactory and thermal sensations and hypnic jerks caused by feelings of falling have been reported (Mavromatis, 1987; Vaitl et al., 2005).

2.8.1.3 One Body Technique (OBT)

The One Body Technique (OBT; Tholey, 1983). for inducing WILDs entails using a modified version of the body scan technique, a technique that is typically used in relaxation and in falling asleep faster (Hubblin, Reilly-Spong, Kreitzer & Gross, 2014). In the body scan technique attention is shifted on different points of the body, noticing how the body feels at each point (Hubblin, Reilly-Spong, Kreitzer & Gross, 2014). In OBT, while attention is shifted to the

different body parts, one must first remain mindful of signs of REM sleep paralysis such as strange sensations, vibrations and distortions of body image. When these sensations develop into sleep paralysis then one must imagine that their body is able to move again and imagine that they are in some other place other than their bed. Success in this method is thought to lead into lucid dreaming (Tholey, 1983).

2.8.1.4 Count Yourself to Sleep Technique (CYST)

The premise of the Count Yourself to Sleep technique is rather simple; the aim is to count to yourself " One, I'm Dreaming; Two, I'm dreaming,..." and to keep counting and remain vigilant while you fall deeper into sleep until one enters dreaming (Tholey, 1983)

2.8.1.5 Tholey's Image-Ego Technique (TIET)

In this technique (TIET), while falling asleep, one is instructed to concentrate on the thought that their body will become imperceptible, while at the same time putting focus on the hypnagogic imagery that starts forming. Once sleep paralysis sets in, one is instructed to visualise that one can perceive, feel, think and act in the dream scenario.

2.8.1.6 Tholey's Combined technique

Tholey's Combined technique combines elements of reflection, intention and autosuggestion. In this context, reflection refers to questioning oneself during the day whether one is dreaming or not, and looking for environmental incongruences or performing certain actions that would result in different outcomes when performed whilst one is dreaming (Stumbrys et al., 2012;

Tholey, 1983). A common reflection technique used is pinching one's nose throughout the day and trying to breathe through the nose - which is impossible when awake (Love, 2013). By doing this one has a higher chance of dreaming about doing this reality check which acts as a "light bulb moment" which induces lucid dreaming, as one can breathe through one's nose in the dream (as of course, they would not actually be physically pinching their nose). This reflection technique is also referred to as a 'Reality Testing' (RT) or 'Reality Check' (RCs; Stumbrys et al., 2012). They have been frequently used in conjunction with other techniques (e.g., MILD and WILD) and as a standalone technique; although it has been found to be much less effective when used without other LD induction techniques (LaBerge, 1988; Taitz, 2011; Stumbrys et al., 2012; Aspy et al., 2017).

The Intention technique of Tholey's Combined technique entails intensively visualizing oneself being in a dream situation and recognising that one is dreaming, before falling asleep. Thus, Intention is similar to the MILD technique but without involving the "mnemonic component" of MILD (Stumbrys et al., 2012).

In the autosuggestion technique a person suggests to himself or herself to have a lucid dream during the night while being in a relaxed state before falling asleep (Tholey, 1983). Findings on the effectiveness of the autosuggestion technique have been inconsistent (Schlag-Gies, 1992; Levitan, 1989) and autosuggestion has been shown to be generally more effective in experienced lucid dreamers (Levitan, 1989), and to be less effective than the RT/reflection technique but produce similar results to the intention technique (Schlag-Gies, 1992).

2.8.1.7 Senses Initiated Lucid Dream (SSILD)

The Senses-Initiated Lucid Dream (SSILD), is a WILD technique that was first developed and posted in a Chinese LD forum by Zhang in 2011 (Zhang, 2013) and then spread out to other international LD-related forums and websites. The SSILD technique was empirically tested for the first time much later by Aspy (2020), who demonstrated that MILD and SSILD are similarly effective at inducing lucid dreams. Aspy (2020) found that the group who practised the SSILD technique induced an average LD rate of 16.9% within a week of attempting the technique, showcasing a similar induction rate with the MILD (16.5%) and RT + WBTB + MILD (17.4%) groups. The whole concept of the SSILD technique is to be focused on what is called "cycles". In each cycle, one is instructed to focus on three senses in a consecutive manner: vision, hearing and somatosensation. Thus, when focusing on vision one is asked to observe any hypnagogic images that may occur. After a while attention is shifted to hearing (eg., external sound, noise inside your head, heartbeat and any hypnagogic auditory hallucinations). The cycle is completed when attention is finally shifted to your somatosensation (eg., sensation of body lying in bed, signs of sleep paralysis and hypnagogic somatosensory hallucinations such as tingling, heaviness, lightness, spinning sensations etc). In the SSILD technique, practitioners are asked to first spent a little time focusing their attention on each sense during the first 4-6 cycles (5-10 seconds spent at each sense). In the later cycles, they are asked to gradually increase duration of attending to each sense so that at least 30 seconds are spent focusing on each sense.

2.8.2 Difficulty in estimating LD induction success rate in cognitive techniques

Estimating the success rate of cognitive LD induction techniques from the literature becomes difficult as studies have:

1) Employed frequent/experienced lucid dreamers (Levitan, 1990; 1991; Levitan et al., 1992; Edelstein & LaBerge, 1992; LaBerge et al., 1994) or non-experienced lucid dreamers (e.g., Purcell et al., 1986; Zadra, 1991; Zadra et al., 1992; Schlag-Gies, 1992; Spoormaker & van Den Bout, 2006; Hickey, 1988), although cognitive LD induction studies by Aspy et al., 2017 and Aspy (2020) have found no significant LD induction rate differences between participants with experience in LD induction techniques vs those who don't.

2) Have tested the techniques in the field (e.g., (Levitan, 1990; 1991; Levitan et al., 1992; Edelstein & LaBerge, 1992; LaBerge et al., 1994; Aspy et al., 2017; Aspy, 2020; or in the lab (Dane, 1984; Dane & Van De Castle, 1974; Galvin, 1993). Although the vast majority of studies evaluating cognitive techniques have been field studies.

3) Have tested the techniques for different durations of time, from as little as one day of trying (e.g., Levitan, 1990; Edelstein & LaBerge, 1992), to more than a month of trying (e.g., Schlag-Gies, 1992; Zadra, 1991; Zadra et al., 1992, Spoormaker & van Den Bout, 2006).

4) Have tried the techniques at different time points, for example, overnight (e.g., Paul, Schädlich & Erlacher, 2014; Voss et al., 2014) or during an AM nap (e.g., Carr et al. 2020; Blanchette-Carriere et al., 2020), therefore circadian rhythm effects could be a possible confound to the LD induction success rate.

2. 9 Pharmacological Methods

Drug applications to aid in lucid dream induction have been investigated with drugs such as Galantamine showing promise in increasing lucid dream frequency (LaMarca & LaBerge, 2012; Sparrow, Hurd & Carlson, 2016; LaBerge, LaMarca & Baird,2018)). Galantamine is a cholinesterase inhibitor, typically used for the treatment of mild to moderate Alzheimer's disease (Takeda et al., 2006), that in specific dosages, enhances human cholinergic receptor activity (Texidó, Ros, Martin-Satué, Lopez, Aleu, Maral, Solsona, 2005). It is postulated that Galantamine can aid in LD induction as it affects cholinergic receptor activity during sleep, which promotes REM-ON neuronal activity, which can lead to shortened REM sleep latency. increased REM density and decreased NREM 3 (Reimann, et al., 1994). In addition, as galantamine is used to improve memory processes (Koontz & Baskys, 2005) it may promote LDs by enhancing cognitive and metacognitive dream ability - a requisite for inducing lucid dreams (Kahan & LaBerge, 1994). It is generally postulated that acetylcholine not only plays a critical role in dream consciousness but also consciousness in general, by significantly contributing in the integration of conscious awareness, with Perry, Walker & Perry (1999; p.273) naming acetylcholine ‘‘a neurotransmitter correlate of consciousness".

A recent study by Sparrow, Hurd & Carlson (2016) on experienced lucid dreamers has demonstrated that galantamine significantly enhanced dream length and vividness, and decreased negative dimensions of dreaming, including fear, violence, and the presence of threatening characters. Following these results, Laberge, LaMarca & Baird (2018) investigated

the effect of combining the WBTB + MILD cognitive LD induction techniques with Galantamine. In a three-night protocol, participants in the study took galantamine before going back to sleep whilst practising the MILD technique and found that the percentage of LD occurrence significantly increased when compared placebo Galantamine dosage. Specifically, the 4mg dosage produced a 27% LD induction success and the 8mg dosage produced 42% LD induction success while the active placebo condition had a 14% LD induction success.

Contrastingly, Kern, Appel, Schredl & Pipa (2017) investigated the effect of L-alpha glycerylphosphorylcholine (a-GPC) on lucid dream induction and dream content. A-GPC is an acetylcholine precursor drug, that can pass through the blood-brain barrier. However, this study found no effect on LDF for this cholinergic agonist.

2.10 Electrical Brain stimulation techniques

More recently and following the neuroimaging findings in lucid dreamers increased frontotemporal activation and an increase in gamma band activity during LD (Voss et al, 2009; Dresler et al, 2012), Voss et al (2014) sought to investigate the effect of applying gamma frontotemporal stimulation using transcranial alternating current stimulation (tACS) on enhancing dream lucidity. Following application of frontotemporal gamma band tACS stimulation at 25 Hz and 40 Hz, Voss et al (2014) reported an increase in reports of dream lucidity in participants inexperienced to lucid dreaming. In this double-blinded study, 27 healthy participants, following 2-3 minutes of uninterrupted, arousal-free REM sleep, received in a counterbalanced fashion over four nights, frontotemporal stimulation at various frequencies (either 2, 6, 12, 25, 40, 70 and 100 Hz or sham), for 30 seconds. The participants were then awakened and asked to complete the LuCiD scale and a dream report. tACS

stimulation at 40Hz increased dream lucidity in regards to LuCiD factors of INSIGHT and DISSOCIATION and at 25Hz increased LuCiD factors INSIGHT and CONTROL, with 77% and 58% success rate, respectively. However, it must be noted that whilst the aforementioned LuCiD factor scores increased, these scores only increased slightly and on average, scores on the five-point LuCiD Likert-scale were far away from being classified as actually reflecting lucid dream consciousness. Hence, we arguably consider the title of Voss et al. (2014) 'Induction of self-awareness in dreams through frontal low current stimulation' to be sensationalist and potentially misleading. Voss et al. (2014) reported that lucidity success rate was assumed when participants' INSIGHT and/or DISSOCIATION scores on the LuCiD scale exceeded the mean by + 2 standard error. However, that does not denote whether one actually experienced awareness of being in a dream. As can be seen in figure 2.4 below (taken from Voss et al., 2014 paper) whilst INSIGHT, DISSOCIATION and CONTROL factors increased,

on average, no participant reported a LuCiD score higher than 1.5 on a 5-point Likert scale (0 = Strongly disagree, 5 = Strongly agree).

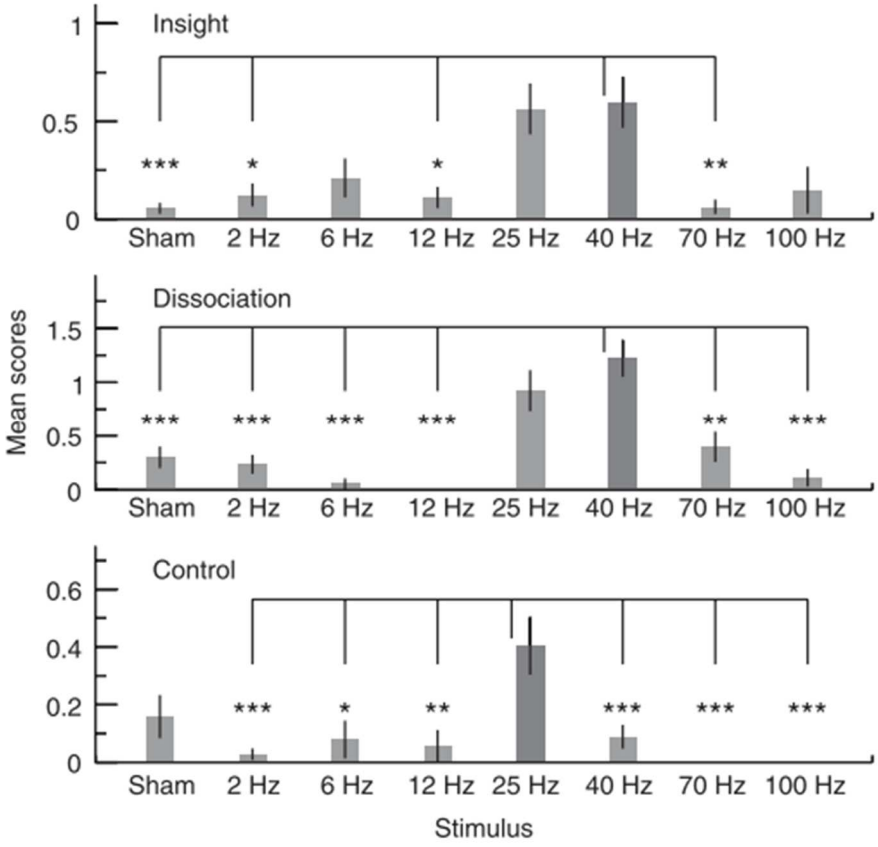

Figure 2.2 The graph is taken from Voss et al. (2014) and showcases the differences in LuCiD scale factors Insight, Dissociation and Control following tACS stimulation (or sham) at the following frequencies: 2, 6, 12, 25, 40, 70 and 100 Hz.

Nevertheless, following Voss et al's (2014) findings, the potential of tACS to reliably induce a lucid dream state or increase dream lucidity to inexperienced lucid dreamers was seen as a breakthrough, prompting in the development and advertisement of LD induction wearable devices such as Aladdin Dreamer and Lucid Catcher in crowd-funding websites which promoted the use of tACS stimulation to induce LDs (Mota-Rolim, Pavlou, Nascimento, Fontenele-Araujo, Ribeiro, 2019). However, subsequent research by Blanchette-Carriere et al. (2020) which used either frontotemporal gamma tACS stimulation or sham stimulation on a larger sample size did not replicate Voss et al. (2014) findings. In general, the effectiveness of transcranial current (tCS) techniques (e.g., tDCS, tACS and tRNS) to directly influence

neuronal circuits has been put in question (Kar & Krekelberg, 2012; Lafon et al., 2017; Vöröslakos et al., 2018; Asamoah, Khatoun, & Mc Laughlin (2019). Particularly, an intracranial study on human cadavers by Vöröslakos et al. (2018) showcased that 4-6 mA current is required to directly affect neuronal circuits, at least double of what tCS devices can produce (with good reasoning as higher than 2 mA current intensity is intolerable). Thus, in the Voss et al (2014) study, the current intensity was sixteen times less than what Vöröslakos et al. (2018) showcased as the minimum intensity to directly affect neuronal circuits. In addition, a previous intracranial study by Lafon et al (2017) that was done on patients undergoing epilepsy surgery, revealed that tACS did not modulate wake EEG (in the theta band) nor did it modulate sleep microstructure EEG events such as SWA or spindles. On the other hand, pulsed auditory stimulation was able to induce SWA and spindle entrainment (Lafon et al., 2017). Vöröslakos et al (2018) postulates that if there exist a tangible effect of tCS, it is through some form of indirect mechanism such as peripheral nerve stimulation. Evidence towards peripheral nerve stimulation can be seen from work done by Kar & Krekelber (2012) and Asamoah, Khatoun, & McLaughlin (2019). Kar & Krekelber (2012) showed that tCS stimulation over the visual cortex evoked phosphenes through a retinal pathway. Asamoah, Khatoun, & Mc Laughlin (2019) showed that any tCS effects are likely due to transcutaneous stimulation of peripheral nerves in the skin, as use of a topical anaesthetic cream (lidocaine/prilocaine) to the stimulated area reduced the expected neural entrainment massively. Due to all these findings on tCS, Mota-Rolim, Pavlou, Nascimento, Fontenele-Araujo & Ribeiro (2019) postulate that it is likely that if any effects of tACS found in Voss et al (2014) were due indirect mechanisms such as increased arousal caused by the sensation of the electro-tactile stimulation, which in turn may have caused key areas involved in LD to activate (Mota-Rolim et al., 2008, 2010; Voss et al., 2009; Dresler et al., 2012).

2.11 External stimulation techniques

"He dreamed of the Reign of Terror during the [French] Revolution. (…). Finally he himself was summoned before the Tribunal (….) and was sentenced to death. Accompanied by an enormous crowd, he was led to the place of execution. He mounted the scaffold; the executioner tied him to the plank, it tipped over, and the knife of the guillotine fell. He felt his head severed from his trunk, and awakened in terrible anxiety, only to find that the head-board of the bed had fallen, and had actually struck the cervical vertebrae just where the knife of the guillotine would have fallen."

(Cited in Freud 1900/2010, pp. 58-59) - This dream illustrates the effect of an external stimulus and the incorporation of the produced somatosensory sensation (headboard of the bed falling on his neck) on the dream content.

External stimulation LD techniques refer to those that present stimuli, such as auditory, visual and tactile stimuli, during REM sleep. The aim is for them to be incorporated into the dream content, in order to alert the dreamer that they are dreaming (Stumbrys et al., 2012). A review by Solomonova & Carr (2019) highlights that studies which aim to incorporate external stimuli during REM sleep (including studies unrelated to LD induction) have reported an incorporation success rate as low as 9% and as high as 87%. In the following paragraphs I will aim to discuss why there is such a high variability in successful stimulus incorporation rates. Subsequently, in Chapter 5, based on the apparent limitations of past studies, a new external stimulation technique and framework will be discussed and tested for its efficacy at inducing LDs. Before delving into the research that has been done on external stimulation LD techniques, this chapter will discuss briefly research done on external stimulus processing in sleep, in fields related and unrelated to LD. The aim of the following sections in this chapter is to provide evidence for

the need to develop an individually adjusted external stimulation technique that will be discussed in more detail in Chapter 5.

2.11.1 External stimuli processing in normal sleep

Sleep is often characterized by a loss of consciousness and reduced responsiveness to external stimuli (Bonnet & Moore, 1982). Studies measuring auditory stimuli arousal thresholds in the various stages of sleep show that a minimum of 70 decibel sound pressure level (dB SPL) sounds are needed to produce awakening of a participant in NREM 2, followed by 83 db SPL in REM and 92dB SPL in NREM 3 (Bonnet et al., 1978). However, the study by Ermis, Krakow & Voss (2009) showcase that on average, less than 60 dB SPL are needed to wake one up from sleep in any given sleep stage. We consider that the discrepancy between Bonnet et al., (1978) and Ermis, Krakow & Voss (2009) may be due to differences in measuring equipment or sample characteristics. For a comparison, 50dB corresponds to levels of normal conversation and 92dB corresponds to sound of a motorcycle <25 ft away from one's bed. Studies have shown that the semantic quality of the auditory stimulus, such as the name of the sleeper, tend to invoke more K-complexes, GSR responses, heart-rate changes and awakenings than other names or sounds of the same intensity (Oswald et al.,1960; Langford et al., 1974; Beh and Barrat, 1965; McDonald et al., 1975; Voss and Harsh, 1998). This suggests that semantic quality and not other sound properties may be the cause for this high-level discriminatory, unconscious response in the participant (often leading to a conscious response, i.e. awakenings). Furthermore, fMRI studies have demonstrated selective activation of the left amygdala and left prefrontal cortex when participants' own names are played during sleep compared to non-significant sound, tone-bursts (Portas et al., 2000; Portas, 2005). It is postulated that the semantic quality/relevance of a sound played in sleep is important for survival, serving a functional role to alert the sleeper of potential threats or other needs such as

awakening a mother to cries of her baby (Formby, 1967; Poitras et al., 1973). The above functional role is further backed by animal studies that demonstrated animal awakenings when meaningful stimuli (or stimuli that had gained meaning) were presented, as opposed to insignificant stimuli (Halperin & Iorio, 1981; Rowland, 1957; Siegel & Langley, 1965; Van Twyver & Garrett, 1972; Maho and Hennevin, 1999).

One of the methods used to study brain response to external stimuli during sleep are evoked potential EEG studies. The evoked potential is the grand-average waveform response to a repeated stimulus and contains components arising from multiple brain sources (Luck & Kappenman, 2012). The earliest components to an evoked potential (<15ms) are surmised to reflect low-level sensory activation while the latter components (>50ms) are thought to reflect higher level cognitive stimulus processing such as assigning semantic quality/relevance to the stimulus (Bastuji et al., 2002; Hennevin et al., 2007). Components of the event-related potential (ERP) are given names such as N1 or N100, P300 and P400 (Luck & Kappenman, 2012). The letter N refers to negative polarity and P refers to positive polarity and the ensuing number refers to the latency in milliseconds that the component roughly appears (Luck & Kappenman, 2012).

The oddball paradigm is an evoked potential paradigm, which has been used to assess sound processing in sleep. In the oddball paradigm, a stimulus is presented repeatedly, establishing an expectation that it will be repeated. At one point, a novel and unexpected stimulus is presented, which elicits a strong negative ERP component potential, called the mismatch negativity (MMN). A weak MMN has been observed to present itself during an oddball paradigm in REM (Loewy et al., 1996; Lowey et al., 2000; Nashida et al., 2000; Atienza et al., 2000), but not in NREM 3 (Sabri et al., 2003; Sabri and Campbell, 2005). A review by Cote

(2002), of oddball-paradigm studies and also the presence or absence of P300 (auditory ERP thought to reflect slow, effortful conscious processing rather than fast and automatic processing) in sleep studies, revealed the classic parietal P300 to be exhibited, but little to no positivity at frontal brain areas, a finding that is consistent with the frontal deactivation of REM. However, the appearance of the P300 during REM as well as findings from studies which show the tendency of external stimuli to be incorporated into the dream content indicate that REM sleep exhibits enhanced information processing capabilities when compared to NREM sleep. Eichenlaub et al (2014), using an oddball paradigm during sleep and wakefulness, looked into brain reactivity (evoked potentials) differences between high DRF and low DRF participants. The authors found that during wakefulness, in response to unexpected first names and the deviant stimuli, the attention-orienting brain response (P3a) and a late parietal response were larger in high DRF than in low DRF participants. During sleep, they observed between-group differences at the latency of the P3a during NREM 2 and at later latencies during all sleep stages. In addition, the authors found that high DRF participants exhibited higher (about double) intra-sleep wakefulness than low DRF participants. This finding is similar to previous findings by Cory & Ormiston (1975) and Schredl et al. (2003) and supports the arousal-retrieval model of sleep by Koulack & Goodenough (1976), which postulates that intra-sleep awakenings or microarousals allow for the encoding of dreams into memory. In regards to the P300 component differences, their results suggest that high DRF is associated with more reactivity to external stimuli than low DRF in both wakefulness and sleep. Thus, the authors suggest that DRF is "associated with a particular cerebral functional organization, regardless of the state of vigilance" (Eichenlaub et al., 2014, p.1206). As mentioned earlier, DRF is repeatedly found to be a significant correlate of LDF in the LD literature and this relationship can be explained by the idea that persons with high DRF exhibit higher cortical activation during sleep which then can give rise to higher cognitive abilities exhibited in LD. Findings by

Eichenlaub et al (2013; 2014) clearly show that high DRF is correlated with higher stimulus reactivity, increased activity in TPJ and mPFC, more intra-night awakenings and microarousals. In addition, findings show that the WBTB technique is crucial in increasing LDF and again, the mode through which it happens is thought to be through rising cortical activations caused by the brief intra-night awakening (Smith & Blagrove, 2015; Stumbrys et al., 2012). It is therefore likely that experimentally increasing cortical activation through external stimulation can not only lead to higher DRF but at the same time increase LD induction rates.

Therefore, the following sections will explore previous research on cognitive effect of external stimuli presented prior to sleeping, during normal NREM sleep, REM sleep and during lucid dreaming.

2.11.2 Stimuli presented before sleep and dream content manipulation

Research on stimuli presented prior to sleep has mixed results. Studies have found no notable effect on dreams after erotic deprivation (Cartwright et al., 1969) or thirst induction (Dement & Wolpert,1958). However, other work has had more positive results. In Roffwarg et al (1978), participants were instructed to wear goggles that filter out all colour wavelengths other than red during the whole day, for a week. Participants reported that their dreams were increasingly being tinted in the same red tone as the days of the week went by. It has also been demonstrated, in Wamsley et al. (2010), that intensely playing a video game before sleep leads to incorporation of the video game's images in the dream content. Similarly, the results from Stickgold et al's (2000) study on amnesic patients demonstrates that images of a game played before sleep have the tendency to be incorporated in their dreams even though amnesic participants have no conscious recollection of playing the game before sleep.

In regard to LD research and stimuli presented prior to sleeping, Carr et al. (2020) trained 41 participants to respond to visual (red LED flashes to the eyes) and auditory stimuli (beeping sound), by visualising a recent dream and subsequently imagining becoming lucid in the dream and performing eye signalling. The intensity of both the auditory and the visual stimuli were adjusted prior to sleeping according to how participants 'felt' that the stimulus would easily be noticed, while at the same time, wouldn't wake them up. Subsequently, participants received the audio-visual cues during REM sleep alternating 15 second intervals. Eye-signal-verified LDs (SVLDs) were reported by half the sample that received external stimulation, while 17% of the sample that received sham stimulation had SVLDs. A criticism of Carr et al (2020) study is that adjusting stimulus intensities based on wake perception and estimation of participants is highly unlikely to have any basis on how the stimuli would be perceived during REM or whether the stimuli would reach their awakening threshold or not. Nevertheless, Carr et al (2020) were the first to investigate the concept of 'Targeted Lucidity Reactivation (TLR)', whereby participants are conditioned to respond to the stimulus prior to sleeping in the hopes of conditioning a lucidity response whilst dreaming when the stimulus is played again during REM. The concept of TLR takes inspiration from another technique called 'Targeted Memory Reactivation' (TMR), wherein stimuli (such as auditory or olfactory cues) associated with previous learning (e.g., serial reaction time task) are presented during NREM sleep to externally reactivate aspects of this learning, leading to increased memory consolidation when tested post-sleep (Oudiette & Paller, 2013; Cairney et al., 2014; Cousins et al., 2016; Cousins et al., 2014). TMR is described further in the following section below.

2.11.3 External stimuli during NREM

External stimuli techniques during NREM sleep present stimuli during NREM sleep in order to either modulate NREM 3 microstructure characteristics (e.g., SWA and spindles) and/or sleep macrostructure (e.g., duration of NREM 3) and/or affect memory reactivation replay (through TMR), all with the aim of affecting memory consolidation processes (see Zhang & Gruber, 2019; Cellini & Capuozzo 2018; Oudiette & Paller, 2013, for review of the NREM external stimulation techniques). The techniques outlined in this section were a crucial inspiration for the development of a theoretical and technical framework of the Individualised Auditory Stimulation (IAS) technique described in Chapter 5.

2.11.3.1 SWA activity modulation techniques

A technique that has been found to improve slow-wave activity effectively is closed-loop auditory stimulation technique (CLAS; Choi, Kwon & Jun, 2020). In CLAS, essentially a neurofeedback protocol is applied during NREM 3 sleep: A delta band frequency bandpass (usually 1-4 Hz) is first applied to the EEG signal and subsequently a threshold is applied, whose aim is to trigger a 50ms pink noise stimulus at the peak of a slow wave in order to enhance SWA amplitude and create a sharper SWA slope. Usually, an adaptive threshold is applied that updates continuously in order to increase the likelihood of the stimulation falling on SWA peaks as SWA peaks can vary in amplitude. As mentioned in Chapter 1, SWA amplitude is decreased and the slope of SWA is shallower with ageing and in cognitive decline, hence reversing these SWA changes is thought to be beneficial (Zhang & Gruber, 2019). CLAS has been found to not only to be highly effective at entraining SWA (Garcia-Molina et al., 2018; Tononi et al., 2010; Ngo et al., 2013; 2015; Ong et al., 2016; 2018; Santostasi et al., 2016; Papalambros et al., 2017;2019), but in many cases also exhibiting cognitive effects such

as: an increase in declarative memory (e.g., Ngo et al., 2013; 2015; Ong et al., 2016; 2018; Papalambros et al., 2017;2019); improved immune processing (Besedovsky et al., 2017) and autonomic function (Grimaldi et al., 2019). Contrastingly, open-loop auditory stimulation (OLAS), i.e., phase-independent auditory stimulation when applied during SWA, while it appears to induce SWA entrainment, does so to a lesser degree than CLAS and in addition, it does not seem to carry the same cognitive effect benefits of CLAS (Weigenand, Mölle, Werner, Martinetz & Marshall, 2016; Simor et al., 2018; Choi, Kwon & Chan Jun, 2020). Even though SWA enhancing effects have been found with transcranial magnetic (Massimini et al., 2007) and electric stimulation (Marshall et al., 2004; Ketz et al., 2018), CLAS is seen as a more promising technique for enhancing SWA, due to the fact that is non-invasive, cost-effective, easy to apply and successful in entraining not only SWA but also showing cognitive benefits (Navarrete et al., 2020). In regards to optimal CLAS parameters, Navarrete et al (2020) demonstrate that the optimal timing is at the peak of the SO and that there are age-related differences in the window of stimulation opportunity, thus suggesting that adaptive CLAS algorithm should be constructed to improve timing of SO stimulation particularly in the elderly population.

2.11.3.2 Spindle modulation techniques

The CLAS technique, in addition to modulating SWA activity, also seems to drive spindle-generator processes (Antony & Paller, 2016; Lustenberger et al., 2018; Ngo et al., 2019; Antony et al., 2019). Attempts to enhance spindle activity through spindle frequency auditory stimulation (11-16 Hz) have been less fruitful (Antony & Paller, 2016; Ngo et al., 2019; Antony et al., 2019), contrasting findings of spindle modulation through spindle frequency range auditory stimulation by Antony & Paller (2017) and Lustenberger et al. (2018).

2.11.3.3 Memory reactivation techniques

As mentioned earlier, Targeted Memory Reactivation (TMR) is a memory reactivation technique whereby stimuli, experimentally paired with learning during a wake task, are replayed during sleep to reactivate learning and subsequently enhance memory consolidation (Oudiette & Paller, 2013; Cairney et al., 2014; Cousins et al., 2016; Cousins et al., 2014). Neurophysiological correlates of consolidation following TMR have been demonstrated for declarative memories (Sterpenich et al., 2014; van Dongen et al. 2014), for procedural memories (Cousins et al., 2016) and for emotional memories (Cairney et al., 2014). TMR traditionally uses auditory stimulation during sleep but a study by Bar et al (2020) has used olfactory TMR. Bar et al (2020) paired an olfactory stimulus (rose odour) with a wake learning task (word-location association task) in either both, or to individual nostrils. Subsequently, the odour stimulus was presented to the participant during NREM 3 sleep (30 second on and 30 second off) and then participants were re-tested post-nap. Results from the study showed that the TMR paradigm can act not only globally but also locally, as post-nap retest showed that reactivation of memories through olfactory stimulation in only one hemisphere during sleep enhanced memory consolidation in learned word-location associations (presented either left or right visual field) stored in the same hemisphere.

2.11.4 External stimuli during REM and dream content manipulation

Various researchers looking at the effect of external stimuli during REM sleep have found that external stimuli have the tendency to be incorporated into the dream content with different

types of stimuli having different incorporation rate success. Dement and Wolpert (1958) used three different types of stimulus during REM: 1000Hz sinus tones, light flashes and water sprayed onto skin. These stimuli produced an incorporation rate of 9%, 23% and 42% respectively. Berger (1963) used an auditory stimulus of the sleeping subject's name with a 40% incorporation rate. Koulack (1969) used electric shocks to the thumb with a 56% incorporation rate. Hoelscher et al. (1981) used neutral and meaningful words with an 11% and 34% incorporation rate respectively. Trotter et al. (1988) used odour stimuli with a 19% incorporation rate. Nielsen et al (1993) used a small pain stimulus with a 31% incorporation rate. Nielsen (1993) using pressure stimulation applied to different limbs (blood pressure cuffs), affected the kinaesthetic content of dreams, with an 87% incorporation rate. Leslie & Ogilvie (1996) rocked participants in a hammock with 25% incorporation rate. Speth and Speth (2016), using a randomized, triple-blinded design, investigated the effect of anodal tDCS stimulation (vs cathodal and sham) over the left motor cortex (C3) in REM sleep. The authors' results suggest that anodal tDCS over the motor cortex during REM sleep (a state implicated in motor development and rehearsal of motor movements for later performance) increased the quantity and quality of spontaneous and athletic motor imagery, as compared to cathodal and sham tDCS (figure 2.6).

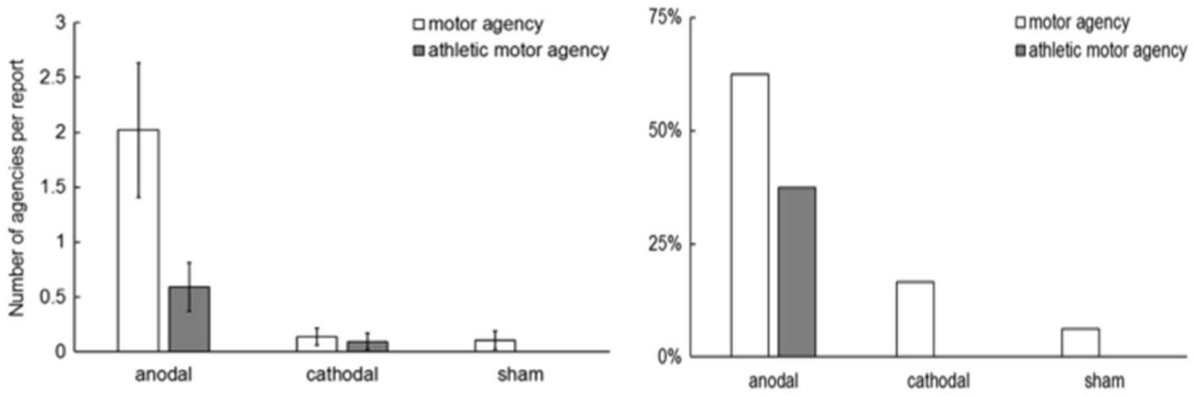

Figure 2.6. Top graph demonstrates the number of motor and athletic agencies per report after anodal, cathodal and sham stimulation of C3. Error bars indicate the standard error of the mean. The bottom graph demonstrates percentage of reports containing one instance or more of motor agency or athletic motor agency per report after anodal, cathodal, or sham stimulation. Taken from Speth & Speth (2016).

However, due to the criticisms mentioned earlier on the ability of tCS techniques to directly affect neuronal circuits and the fact that tDCS in Speth & Speth (2016) was only applied over the motor cortex and not in other areas of the cortex, the supposition that changes in the dream content were caused by direct stimulation of the motor cortex is questionable. It is likely that the dream incorporation effects they observed could have be caused by the incorporation of mildly noxious electro-tactile sensations into the dream content/scenario. Hence, placing tDCS electrodes elsewhere, not only at a different location on the head but also on the rest of the body would likely produce a similar effect. In addition, similarly to Asamoah, Khatoun & Mc Laughlin's (2019) results, applying a topical cream to the stimulated area would likely reduce or eliminate any changes to the dream content caused by tDCS.

2.11.5 External stimuli during REM to induce lucid dreaming

Most used external stimulation LD induction techniques include the use of visual stimuli, in the form of light flashes to the eyes, acoustic stimuli, vibrotactile or electro-tactile stimulation (Stumbrys et al., 2012). Other external stimulation techniques such as vestibular stimulation (Leslie & Ogilvie, 1996), deployed by rocking participants in a hammock, and water stimulation deployed by splashing water to the face or hands of participants (Hearne, 1978), were found to be ineffective (Stumbrys et al., 2012).

2.11.5.1 Light stimulation

Light stimulation during REM sleep for the purpose of inducing LDs has been investigated in a total of five studies (table 2.1). Two studies were carried out in a sleep laboratory experiment (LaBerge, Levitan, Rich, & Dement, 1988; Paul, Schädlich & Erlacher, 2014) and the

remaining three were field studies utilising commercially available LD induction devices (DreamLight, DreamLink, Nova- Dreamer) developed by the LaBerge's lab group (LaBerge, 1988; LaBerge & Levitan, 1995; Levitan & LaBerge, 1994). Light cues have been demonstrated to be incorporated into dream content and induce lucid dreaming (LaBerge et al., 1988; LaBerge & Levitan, 1995; Paul, Schädlich & Erlacher, 2014) but their effectiveness at inducing LDs is quite low when compared to other external stimulation and cognitive LD induction techniques. LD induction rates tend to improve when paired with cognitive techniques such as the MILD technique and RT (LaBerge, 1988; Levitan & LaBerge, 1994). In the latest study to investigate light stimulation by Paul, Schädlich & Erlacher (2014), the only research group to test this approach besides LaBerge's research group, only 10% of participants experienced SVLD (N = 10), while 38.9% reported that the visual stimulation was incorporated without inducing an LD. The light stimulation that participants received was 1 Hz for five seconds and its intensity and duration remained static throughout the whole experiment.

Two problems can be identified with light stimulation techniques. Firstly, the light stimulation lacks the semantic quality that can alert the dreamer that they are dreaming, which is evidenced by the much higher stimulus incorporation rate when compared to the LD induction rate in Paul, Schädlich & Erlacher, 2014. Hence, combining light stimulation with a TMR pre-sleep training paradigm, similar to that employed by Carr et al. (2020), and/or using a stimulus with higher semantic quality might increase LD induction rate. Secondly, presenting external stimuli without adjusting stimulus properties (such as intensity, duration and presentation rate) to the individual is likely to decrease both stimulus incorporation and LD induction rates. As mentioned in Chapter 1, the way in which the sleeping brain attenuates external stimuli varies from person to person (e.g., by age; Zepelin, Cathleen, McDonald & Zammit, 1984; Busby, Mercier & Pivik, 1994), hence adjusting stimulus properties to the individual should be

favourable. Indeed, Appel, Pippa & Dresler (2017) agree with this position and postulate that the main difficulty of external stimulation techniques rests in the proper adjustment of the stimulus intensity in a way that it is not too low in intensity that the stimulus fails to incorporate and not too high that it causes awakenings. Further evidence that adjusting stimulus properties to the individual ATs should improve stimulus incorporation and LD induction rates come from the higher LD induction success rates observed in previous studies by Laberge's lab which exhibited much larger LD induction rates (LaBerge, Levitan, Rich, & Dement, 1988; LaBerge, 1988; LaBerge & Levitan, 1995; Levitan & LaBerge, 1994). For example, in LaBerge, Levitan, Rich, & Dement (1988), participants were instructed to use LD induction devices developed by his lab, at home, prior to sleep lab testing days and to attempt to adjust light stimulus intensity accordingly so that the stimulus would be presented as high as possible without causing an awakening. Subsequently, in the lab, participants received light flashes during REM sleep at the recorded stimulus intensity levels acquired from the at-home studies (LaBerge, Levitan, Rich, & Dement, 1988). Both stimulus semantic quality and stimulus properties adjustments issues/limitations will be addressed in Chapter 5, where a theoretical and technical protocol is proposed.

2.11.5.2 Acoustic stimulation

Auditory stimuli have been applied in six sleep lab studies (Kueny, 1985; Laberge, Owens, Nagel & Dement, 1981; Ogilvie et al., 1983; Kumar, Sasidharan, Kumar Nair & Kutty, 2018; Carr et al., 2020) and in one field study (Reis, 1989). Out of these six, three utilised solely auditory stimulation (Laberge, Owens, Nagel & Dement, 1981; Ogilvie et al., 1983; Reis, 1989). Whereas, in Kueny (1985), sixteen participants underwent a 3 week MILD training programme and were then tested in the lab during a four non-consecutive night sleep lab

protocol, where auditory stimuli (voice stimuli "Remember, this is a dream" or a or a musical tone), that were either static or increasing in volume, were evaluated. Kueny (1985) found that auditory stimuli that are gradually increasing in intensity are more effective than static ones but surprisingly there were no differences in LD induction rate between voice and music tone stimuli. Kumar et al. (2018) combined auditory stimulation in the lab (a voice repeating "this is a dream" for 25 seconds with an interstimulus interval of 50 seconds) with a 3-month prior cognitive training (Tholey's Combined Technique) and Carr et al. (2020) combined auditory stimulation (beep sound) with cognitive training (TLR) and light stimulation. The methodology used in Kumar et al. (2018) induced LDs during the PSG study in five out of six participants who underwent cognitive training vs one out of five who did not. Kumar et al's (2018) voice stimulus had a standardised volume intensity level for all participants. In Carr et al. (2020), TLR + auditory + light stimulation combination technique induced LDs in 50% of participants, a significant increase when compared to the control group, which received sham stimulation and had a 17% LD induction success rate. Both in Carr et al. (2020) and in Kumar et al. (2018) studies stimuli were not adjusted to individual ATs. As mentioned earlier, in Carr et al. (2020) stimulus intensity was adjusted during wakefulness at a level that participants reported that they 'felt' that the stimulus would easily be noticed without waking them up. This technique of adjusting stimulus properties during wakefulness is unlikely to be as accurate at predicting actual ATs as the technique used by LaBerge's group (e.g., LaBerge, Levitan, Rich, & Dement, 1988) or in Erlacher et al. (2020). In LaBerge's studies attempts to set stimulus intensities to individual ATs involved investigating different stimulus intensities during sleep in nights prior to test nights, for each participant and in Erlacher et al. (2020) auditory stimulus volume was adjusted in the latter part of the night to a level slightly lower than the volume level that woke participants up in the first part of the night. The study protocol in Chapter 5 takes inspiration

from voice stimulus studies (e.g., Kuney, 1985; Kumar et al. (2018), from Carr et al. (2020) TLR protocol and Erlacher et al. (2020) stimulus volume adjustment protocol.

2.11.5.3 Vibro-tactile stimulation

In total, two studies utilised vibro-tactile stimulation. One was a field study by Reis (1989) and the other was a sleep lab study by Paul, Schädlich & Erlacher (2014). Results from Reis (1989) indicated that when vibro-tactile stimulation was combined with reflection it resulted in LDs, but, according to Stumbrys et al. (2012) LD induction techniques review, due to the condition variability (e.g. number of training sessions received, their durations, etc.) the generalisation of Reis (1989) findings is hard to interpret and was given a poor methodological score. Paul, Schädlich & Erlacher's (2014) study on vibro-tactile stimulation, targeting either the index finger, wrist or ankle, yielded the best results compared to a visual stimulation group. The vibro-tactile stimulation group which received vibro-tactile stimulation of the index finger experienced a 42.9% stimulus incorporation success over 24 stimulated REM periods but no reports of LDs. The wrist or ankle vibro-tactile stimulation group stimulus incorporation self-reports exhibited a 48.1% success rate over 36 stimulated REM periods and two reports of LDs (7.4%). In contrast to the light stimulation group, where participants received fixed intensity stimulation, the vibro-tactile groups received vibro-tactile stimulation that increased in intensity for every stimulated REM period. Hence, it is difficult to ascertain whether vibro-tactile stimulation per se is more successful at becoming incorporated into the dream content than light stimulation. In addition, the fact that the stimulus incorporation rate is much higher than the LD induction rate points to the fact that just like light stimulation, the semantic quality of the stimulus is lacking and may be preventing the dreamer from becoming aware that they are dreaming. Moreover, the addition of pre-sleep cognitive training, such as the TLR

technique used in Carr et al (2020), is likely to increase LD induction rates, through a conditioned stimulus response whilst dreaming.

2.11.5.4 Electro-tactile stimulation

Hearne (1983) applied electro-tactile stimulation to the wrist in a sleep lab experiment, achieving lucidity in eleven out of twelve participants, although lucidity caused by the stimulus was attributed to only ten out of twelve participants, as one participant became lucid after falsely perceiving stimulation. It must be noted that in Hearne (1983) electric stimulation was adjusted to the individual as the electric shock level increased until their thumb twitched due to median nerve stimulation. However, as there was no control group, it is difficult to ascertain how successful electro-tactile stimulation is. Due to the arguments put forth that tCS techniques do not directly affect neuronal circuits but act through peripheral nervous stimulation it can be argued that tCS studies from Voss et al (2014) and Blanchette-Carriere et al. (2020) also belong in the electro-tactile stimulation group of techniques.

2.11.5 External stimuli during lucid dreaming

In contrast with studies on the effect of external stimuli during the various stages of normal sleep, the effect of external stimuli during lucid dreaming has not been studied as much. Presented below are some preliminary studies investigating the effect of external stimuli on lucid dreaming.

Strelen (2006) in an EEG study, using an odd-ball paradigm, demonstrated that lucid dreamers could consciously discriminate between two types of short tones (high vs. low tone) by responding in real-time with predefined eye movements in response to the tonesand that those who accomplished this task evoked P300 potentials. Oldis (2010) discussed the idea of using different stimuli cues and body signal cues to send out predetermined messages, with the possibility of being used in what he called "multi-player dream games", with multiple lucid dreamers sending fixed cues to each other. Subsequently, Oldis & Oliver (2012) used a light flash stimulus (light bulb on or off) and a predetermined eye movement pattern to send a signal externally into the dream and back to the external world and attempted to send a cue from one dreamer to another, succeeding only once.

Appel's (2013) master's thesis looked into external communication with a sleeping person. He developed a theoretical Sleep Communication Framework to aid in the future development of sleep communication. Appel (2013) also used an auditory Morse code system of presenting mathematical calculations for the lucid dreamer to solve in the dream with corresponding eye movements with 40% incorporation success, but with a low participant sample. Three participants successfully received the auditory Morse codes corresponding to mathematical equations and were able to solve them, sending their answers back to the experimenter.

The latest study to look into real-time communication between experimenters and dreamers was by Konkoly et al (2021). The paper reports results from four independent scientific teams based in France, Germany, the Netherlands and the USA. The teams used a variety of two-way communication tasks including asking participants to solve spoken maths questions (USA and Netherlands), solve maths questions indicated by tones and lights (Germany), answer yes/no questions and discriminate between tactile, speech and light stimuli, whilst lucid dreaming

(France). Participants were able to respond to these tasks by signalling with their eyes (USA, Germany and the Netherlands; a left and right eye movement equals one and each successive left-right movement was plus one) or by contracting their fascial muscles (France; zygomatic muscle for yes, corrugator muscle for no). Lucidity was achieved through the TLR (USA and the Netherlands), WBTB (Germany) and spontaneously (France; experienced lucid dreamer with narcolepsy). In total, 36 individuals participated in the studies and two-way communication was attempted in a total of 56 sessions over a total of 158 occasions following SVLDs. Overall, SVLDs were achieved in 26% of the sessions during which 47% managed to respond correctly to the questions at least once. The paper does not disclose what the questions or stimuli properties were, such as intensity or presentation rate, or whether they were static or adjusted during wake or whilst in REM sleep.

Before moving onto the applications and benefits of LD research, the table in the subsequent six pages provides a chronological publication ordered list of all external LD induction stimulation studies, that have been published from 1981 up until April 2021 (table 2.1).

Table 2.1. Chronological publication ordered list of all external LD induction stimulation studies, that have been published from 1981 up until April 2021. External stimulation study data from 2012 and before replicated from Stumbrys, Erlacher, Schädlich & Schredl (2012) systematic review of LD induction techniques. A "Stimulus properties" column was added to describe in further detail the stimulus properties that were used (if disclosed).

No	Reference	Type	Methods	Sample	Techniques	Stimulus properties	Main results
1	Hearne (1978)	Sleep lab (within)	1) 1 night in a lab (+adaptation night before) 2) 2 awakenings during late REM periods: (a) experimental condition -after splashing some water on their face or hand with a syringe; (b) control condition – only standing with a syringe (without splashing water). 3) Dream reports rated by judges	N = 10 (university students; 2M/8F)	Water stimulus	N/A	1) None of the participants had LDs. Water-spray theme was present in 6 out of 10 experimental reports, but not in in 10 control reports
2	LaBerge et al. (1981)	Sleep lab (within)	1) 1–2 nights each 2) 5–10 min after beginning of each REM period, phrase ''This is a dream'' was played	N = 4	Auditory stimulation	1) Volume increasing gradually	2) 15 trials in total, lucidity in 5 (33%) cases. Incorporation with lucidity: 3 (20%) 3) Incorporation without lucidity: 2 (13%) Lucidity without incorporation: 2 (13%) 4) Awakening without incorporation: 8 (53%)
3	Hearne (1983)	Sleep lab (within)	1) 1 night each 2) 4 electric impulses to the wrist during REM sleep 3) One ''catch trial'' (awakening after no stimulation)	N = 12 (mostly students; 12 F)	Electric stimulus	1) Output level of electric shock unit increased after each set of impulses from low to high level at which thumb twitched due to median nerve stimulation	1) 6 participants got lucid; 2 participants became lucid but woke up at signalling; and 1 participant falsely perceived stimulation and became lucid
4	Ogilvie et al. (1983)	Sleep lab (within)	1) 1–4 nights in a lab 2) Acoustic stimulus (buzzer) after 15 min of REM in the presence of either high or low REM activity. 3) Participants were asked to signal with their eyes after a stimulus. 4) Awakenings after eye signalling or 30-60 s after stimulus	N = 8 (lucid dreamers)	Auditory stimulation	N/A	1) Total: 57% lucid, 21% prelucid, 22% non-lucid dreams 2 (poor) 2) Spontaneous eye signaling (N = 14): 64% lucid, 27% prelucid, 22% non-lucid 3) Cued high (n = 16): 43% lucid, 21% prelucid, 36% non- lucid

							4) Cued low (n = 15): 69% lucid, 12% prelucid, 36% non- lucid
5	Kueny (1985)	Sleep lab (within/between)	1) 3 weeks MILD training program 2) 4 non-consecutive nights in a lab each: a. 1st and 2nd nights: MILD only; b. 3rd and 4th nights: MILD + acoustic stimulus during REM.	N = 16	Auditory stimulation, MILD	1) Voice ‘‘Remember, this is a dream’’, 5 dB increase every 20 s (Step-Voice) 2) Voice ‘‘Remember, this is a dream’’, 4 dB increase every 4 min (Constant-Voice) 3) Musical tone, 5 dB increase every 20 s (Step-Tone) 4) Musical tone, 4 dB increase every 4 min (constant-tone)	5) MILD only: 6 confirmed LDs from 5 participants (19 reported LDs from 5 ps) 6) MILD + acoustic stimulus: 5 from 5 (22 from 9) 7) Step-Voice: 3 from 3 (12 from 4) 8) Constant-Voice: 1 (1) 9) Step-Tone: 0 (5 from 4) 10) Constant-Tone: 1 (4 from 2) Trend ($p < .1$) for Step condition to be more effective than constant.
6	LaBerge, Levitan, Rich, & Dement, 1988 and LaBerge (1987)	Sleep lab (within)	1-5 nights per participant. Flashing light during REM sleep	N = 44	Light stimulation	1) Light intensity was adjusted to individual ATs during sleep prior to experimental nights 2) Stimulus presentation rate was fixed (2 Hz)	1) In total 55% experienced LDs (including 5 who never had LDs in lifetime). 2) 22% (N = 11) experienced LDs post-stimulus presentation but not triggered by stimulus 3) 66% experienced LDs by being cued for the light stimulus (including 2 out of the 3 subjects with no prior LD experience)
7	LaBerge (1988)	Field (within)	8 weekly group meetings; participants had access to DreamLight devices	N = 49	Light stimulation, MILD, reality testing	1) Light intensity was adjusted to individual ATs during sleep prior to experimental nights 2) Stimulus presentation rate was fixed (2 Hz)	1) Baseline: 3.7% of LDs 2) DreamLight without MILD: 5.5% LDs 3) MILD without DreamLight: 13% LDs 4) MILD with DreamLight: 20% 5) LDs DreamLight usage correlation with LDs: $r = .098 \pm .095$, $p < .022$ 6) MILD: $r = .124 \pm .087$, $p < .003$ 7) Reality testing: $r = .036 \pm .102$, $p < .24$
8	Reis (1989)	Field (within)	Field (within) 1–4 nights each; varying conditions (in some cases individual	N = 8 (4M/4F)	Vibration, acoustic	N/A	tion + reflection (5 participants; 13): 2 LDs from 2 participants tion only (1 p; 2 n): 0 LDs

			training sessions varied in kind, number and length)		stimulation, reflection		l only (1 p; 1 n): 0 LDs Vibration tion + sound + reflection (1 p; 3 n): 2 LDs
9	Levitan & LaBerge (1994)	Field (within)	28 days of dream diary	N = 46 (lucid dreamers: 32M/14F)	MILD, reality testing, hypnotic induction, light stimulation	1) Not disclosed but likely a past protocol was used (e.g., LaBerge, 1988)	2) Baseline (last 6 months): 1 LD in 7 nights 3) Nap (a): 1 LD in 11 nights (5 LDs in total) 4) Nap (b) 1 LD in 2 nights (20 LDs) 5) Nap (c): 1 LD in 1.6 nights (25 LDs) 6) 50 out of 189 naps dreams (27%) were lucid, while only 3 out of 235 night dreams (1.3%)
10	LaBerge & Levitan (1995)	Field (within)	4-24 nights (M = 11), 2 conditions: light stimulation and sham stimulation.	N = 14 (lucid dreamers: 10M/4F)	Light stimulation	1) Light intensity was adjusted to individual ATs during sleep prior to experimental nights 2) Stimulus presentation rate was fixed (2 Hz)	1) 162 reports (81 in each condition) 2) 32 LDs in total: 22 (69%) Q-ON and 10 (31%) Q-OFF. 3) Mean rate (participant/night): Q-ON 0.30 ± 0.24; Q-OFF 0.09 ± 0.15 ($p < .025$) 6 LDs (5 participants) were triggered by a cue (6 in Q-ON, 0.071 ± 0.10 vs. 0 in Q-OFF; $p < .025$) 4) 8 LDs (6 ps) were initiated by the Reality Testing Button (6 in Q-ON, 0.091 ± 0.16 vs. 2 in Q-OFF, 0.016 ± 0.04; $p < .10$) 5) 18 LDs (9 ps) had dreams triggered by any occurrence of the device (Q-ON, 0.174 ± 0.21 vs. Q-OFF, 0.04 ± 0.09; $p < .05$)
11	Leslie & Ogilvie (1996)	Sleep lab (within)	1) 2 nights each sleeping in a hammock; 2) 2 counterbalanced conditions: stationary hammock (control) & rocking hammock 3) Reports from 2nd–4th REM periods. 4) Measures included self-reflectiveness scale and mentation continuum scale	N = 7 (university students)	Vestibular stimulation	Hammock was rocked at at 1 Hz frequency for 5 min during REM.	1) 45 valid reports, subset of 28 REM periods (4 per participant) used 2) Peak self-reflectiveness (PSR): rocking in early morning (M = 4.90) and late morning (4.62) vs. stationary early (2.95) and late (4.43) ($p < .05$) 3) Mentation continuum (MC): rocking early (3.00) and late (1.91) vs. stationary early (1.05) and late (2.33) (p 6 .05) 4) PSR and MC correlation r = .80 (p 6 .001)

							Lucid: 25% (6 out of 24) of rocking dreams vs. 14% (3 out of 21) of control dreams
12	Paul, Schädlich & Erlacher (2014)	Sleep lab (within/between)	1) Two consecutive nights 2) Stimulation started after 5 mins of REM in the 3rd REM period and after 10 mins of REM in subsequent REM periods. 3) Three conditions: a) Visual stimulation (Study 1) b) Tactile stimulation – index finger (Study 1) c) Tactile stimulation – wrist or ankle (Study 2)	Study 1: N = 10 (5M/5F) Study 2: N = 14 (7M/7F)	Visual, tactile stimulation	1) Visual stimulus: Fixed intensity (lux value unknown) flashing lights at 1 Hz for 5 s, in each minute, for five minutes before awakening 2) Tactile stimulation – index finger: vibrating motor for 2 seconds max every one minute, for five minutes before awakening 3) Tactile stimulation – wrist/ankle: 2 seconds max every one minute, for five minutes before awakening a. Stimulation lasted 1 s at lowest intensity on 1st presentation and increased in intensity until max level. Subsequently if no awakening or incorporation occurred stimulation duration increased to 2 s.	1) Visual stimulation: 1 out of 10 participant had an SVLD (5.6 % of all dream reports). a. 38.9% of dream reports stimulus was incorporated 2) Tactile stimulation – index finger: No LDs reported by 10 participants. a. 42.9% of dream reports stimulus incorporated 3) Tactile stimulation – wrist/ankle: 2 participants had SVLDs a. 48.1% of dream reports stimulus was incorporated
13	Voss et al. (2014)	Sleep lab (within/between)	1) Four-night protocol 2) Frontotemporal tACS stimulation or sham after 2-3 minutes of uninterrupted, arousal-free REM sleep 3) Participants awoken 5-10 s post-stimulation 4) Double-blind study	N = 27 (15F/12M)	tACS stimulation	1) tACS stimulation at 250 µA peak to peak intensity 2) Frequencies: either 2, 6, 12, 25, 40, 70 and 100 Hz or sham), for 30 seconds.	1) LuCiD factors INSIGHT, DISSOCIATION and CONTROL increased following tACS stimulation at 25 and 40 Hz 2) These LuCiD factors increased 2+ standard error over the mean at 58% of the participants at 25 Hz and 77% at 40 Hz tACS stimulation
14	Kumar et al. (2018)	Sleep lab (within/between)	1) 1 group (N = 6) went through 3-month training in the Tholey-combined cognitive LD technique, whereas control group (N = 5) did not.	N = 11 (11M) who had never experienced	Tholey's-combined technique, auditory stimulation	1) 25 s pre-recorded voice "this is a dream" presented at 35 – 45dB	1) Tholey's-combined technique group: 5 out of 6 participants reported LDing during experimental night 2) Control group: 1 out of 5 participants had an LD during experimental night.

			2) Baseline PSG study prior to cognitive training 3) During experimental night participants were exposed to a voice stimulus in REM that informed them that they are dreaming	LDs in their lifetime			
15	Blanchette-Carriere et al. (2020)	Sleep lab (within)	1) Participants had two morning naps in total with tACS stimulation in one and the other sham (order counterbalanced)	N = 33 (22F/11M)	tACS	1) 40 Hz tACS tACS stimulation at 250 μA peak to peak intensity 2) Stimulation duration: 2.5 min in 5 cycles of 30 s stimulation-on/ 30 s stimulation-off	1) tACS: SVLDs occurred in 5 out of 27 (18.5%) trials 2) Sham: SVLDs occurred in 4 out of 23 (17.4%) trials.
16	Carr et al. (2020)	Sleep lab (between)	1) Single morning nap session 2) Participants received TLR training for 20 minutes prior napping to associate audiovisual stimulation cues to becoming aware of their inner-state and to notice incongruences to normal waking experience 3) Participants were split into cued and non-cued groups 4) Participants in the cued group received audiovisual stimulation as soon as phasic REM was detected	N = 41 (29F/12M)	TLR, auditory, visual stimulation	1) Light stimulus: red LED light, that flashed 3 times with a rate of 500 ms on/off 2) Auditory stimulus: 500/700/900 Hz beeping tones (200 ms on/off at each acending frequency) 3) Stimulus intensity was calibrated during the training phase at a level that participants estimated that it wouldn't wake them up	1) 07:30 AM Cued group (N = 14): 2) a. SVLDs: 7 b. Non-SVLD: 7 i. Non-LD: 3 ii. Signal only:2 iii. Report only: 2 3) Non-cued group (N = 12): a. SVLDs: 2 b. Non-SLVD:10 i. Report only: 1 ii. Non LD: 9
17	Erlacher et al. (2020)	Sleep lab (within)	1) 6-day training period: participants chose a mobile ringtone and responded with a reality check each time it was heard in the day. Experimenter also called twice in the evening. 2) Participants went through two overnight sleep studies, sham or stimulation night. In stimulation night participants received auditory stimulus on the 3rd REM sleep period onward. Auditory stimulus	N = 12 (4F/8M)	Reality Check, Auditory stimulation	1) Wake ringtone:7s musical ringtone, consisting of 5s constant volume and 2s fade-out at the end 2) REM ringtone: a. 7s music ringtone set to lowest perceptible level (according to each participant) during wake. b. During first two REM periods volume increased by 2% until AAT was reached	1) Stimulation LD induction rate: 5/12 participants (41.7%) – However 1 LD prior to stimulus presentation 2) Sham LD induction rate: 8.3%

			volume increased overtime unti ATs where reached			c. During 3rd REM period onwards stimulus was set to -9% of AAT and increased by 1% until AAT was reached or until 10 stimulations were given	

2.12. Benefits of lucid dreaming - Why utilize lucid dreams?

2.12.1 Study of consciousness and cognitive research

Experimentally activating different areas of the brain while in REM sleep could provide significant insights into how waking consciousness is formed. Models of consciousness such as AIM (Hobson, 1990) and SoC (Voss & Voss, 2014) described above need to be able to explain a variety of conscious phenomena including lucid dreaming, to be valid.

The state of lucid dreaming can also help us answer cognitive research questions. For example, Windt et al. (2014) tested experienced lucid dreamers to conduct research on sensory attenuation and predictive processing frameworks through a self-other tickling paradigm. The tickling paradigm was used to investigate whether sensory attenuation and the self-other distinction continues independently of external sensory input. The inability to tickle oneself is thought to be due to self-generated actions having a dampened sensory consequence from being able to predict on-coming sensory experience though sensory feed-forward information and proprioceptive feedbacking coming from the tickling hand (Blakemore et al., 2006). Research into conditions with self-other disturbances, such as schizophrenia, reveals that schizophrenics are able to tickle themselves (Blakemore et al.,2000). Prior to Windt et al (2014), the self-other tickling paradigm has also been used in sleep by Blagrove et al. (2006). In Blagrove et al (2006), it was demonstrated that participants awoken from REM sleep were able to tickle themselves, with the authors attributing this effect to "a deficit in self-monitoring and a confusion between self and external-stimulation accompany REM dream formation" (Blagrove et al., 2006, p. 291). In Windt et al (2015) participants, whilst lucid dreaming, were instructed to self-tickle themselves or have dream characters tickle them. Windt et al. (2015) preliminary results showed that self-tickling and non-self-tickling produced the same outcome of being

self-tickled when awake. Their results were thus in contrast from post-REM tickling results by Blagrove et al (2006), but the authors caution interpretation of their results due to a variety of study limitations and differences (low sample size, online study, differences in the imagined methods of tickling, etc).

Recently, Raduga, Zhunusova, Shashkov & Sevcenko (2020) investigated whether it was possible to create pain during lucid dreaming and whether pain would be maintained upon awakening. Overall, of the 151 participants who took part in the field study, 74 experienced pain during lucid dreaming and 28% continued experiencing pain that persisted for a few seconds (about 1/3 of these participants) to a few minutes after waking. Due to the fact that the majority of these participants (about 2/3) reported that they continued experiencing pain several minutes after waking up, the pain experienced during wakefulness cannot be solely attributed to hypnopompic hallucinations. The authors surmise that through LD, the reverse effect could possibly be achieved (reduction of pain) but this interesting supposition clearly warrants further exploration.

Another clinical use that research into the neurobiological profile of LD is that it may help us establish brain activity markers of self-awareness, particularly for determining whether unresponsive patients who have suffered a traumatic brain injury aphasia or motor impairments, have retained the capacity for self-awareness (Baird, Mota-Rolim & Dresler, 2019). A final clinical research use for LD is using it as a model of insight in psychiatric conditions where insight is impaired such as in schizophrenia (Baird, Mota-Rolim & Dresler, 2019). Studies comparing brain activity differences between normal dreaming (i.e., lack of insight into the fact that what is experienced is a dream) with lucid dreaming showcase a significant brain region similarity with psychotic patients with impaired insight (Dresler et al.,

2015; Mota, Resende, Mota-Rolim, Copelli and Ribeiro, 2016). Of note is that schizophrenic patients often lack insight of having their condition (Baier, 2010; (Lincoln, Lüllmann & Rief, 2007) with higher decrease in insight being associated with more relapses, re-hospitalizations and poorer therapy success (Mintz, Dobson and Romney, 2003).

2.12.2 Psychotherapy

Previous research has shown that lucid dreaming can be beneficial in psychotherapeutic terms, such as in the treatment of PTSD and people who experience recurrent nightmares (Gavie, 2010; Holzinger Klösch & Saletu 2015; Zadra & Pihl, 1997; Spoormaker & Van Den Bout, 2006; Lancee, Van Den Bout & Spoormaker, 2010). When having nightmares, the amygdala is overactivated, while the pre-frontal cortex is largely inactivated, while, during lucid dreaming, the activation of the prefrontal cortex can lead to an inhibition of the amygdala's over-activity (Levin & Nielsen, 2007; Dresler et al., 2012). By turning a nightmare into a LD, the dreamer could potentially harness this prefrontal activation to choose to change the dream scenario from a nightmare to a neutral or a positive dream. This is particularly important in PTSD, where recurrent nightmares and poor sleep are a major driver of poor mental health (Lamarche & De Koninck, 2007).

Lucid dreaming therapy (LDT) has been shown to improve nightmare frequency, either as a standalone treatment (Zadra & Pihl, 1997; Spoormaker and Van Den Bout, 2006) or as an additional treatment to Gestalt therapy (Holzinger et al., 2015). Although LDT in Holzinger et al. (2015) was shown to improve treatment outcome when combined with Gestalt therapy when compared to using Gestalt therapy alone, Lancee, Van Den Bout & Spoormaker (2010) found not improvement in adding LDT to imagery rehearsal therapy. Further to treating PTSD

symptoms, phobias could potentially be treated with the use of lucid dreaming, in the form of exposure therapy (LaBerge & Rheingold, 1990).

2.12.3 Improving motor skills

Exploratory lucid dream research has demonstrated that lucid dreams can help improve motor skills and has therefore been applied in sport performance enhancement (Stumbrys, Erlacher, & Schredl, 2016; Erlacher & Schredl, 2010; Erlacher & Chapin, 2010; Erlacher, 2005; LaBerge & Rheingold, 1990; Tholey, 1990), effectively act as a form of mental rehearsal/imagery. Mentally performing physical actions (i.e., motor rehearsal, a variant of mental rehearsal) is a well-known method used in sport science, which has been shown to have a significant positive effect in increasing motor performance (Hall, Buckolz & Fishburne, 1992; Yágüez et al., 1998; Lejune, Decker & Sanchez 1994), even increasing muscular strength (Yue & Cole, 1992), and is supported by several meta-analyses (Feltz & Landers, 1983; Driskell et al., 1994). Evidence for the above comes from Decety (1996) and Dresler et al. (2011) who demonstrated that, to some extent, imagined, dreamed and executed actions share the same central neural structures. Furthermore, it has been demonstrated by Dresler et al. (2011) in an fMRI/NIRS study that in addition to imagined actions during wake activating the same structure as actually performing them, dreamed actions also the activate same brain areas (Dresler et al., 2011).

Moreover, using the Betts Inventory (Gackenbach, Prill, & Westrom, 1983), lucid dreaming has been linked to waking imagery vividness in visual and auditory imagery (Hearne, 1983), to gustatory, kinaesthetic, olfactory and tactile waking imagery tasks (Kueny, 1985), and overlaps with the mental training of motor-imagery (Erlacher & Schredl, 2008, 2010; Tholey, 1990). Taken all together, we postulate that dreams are a more complete sensory imitation of waking life than attempts to visualise something in one's mind's eye whilst awake (LaBerge

& Rheingold, 1990). Hence "lucid rehearsal" could enhance motor skills more than wake mental rehearsal (Erlacher & Chapin, 2010).

A recent example of motor skill enhancement through lucid dreaming practices was by Schädlich, Erlacher &Schredl (2016). They used a pre-post design (evening and morning) a dart throwing task to determine change of performance (post practice improvement effects) between a group of lucid dreamers, a physical practice group and a control group. The dart throwing task was chosen as it has been demonstrated by several studies that mental practice seems to influence dart throwing performance (Kremer, McNeil, Shinners, & Spittle, 2009; Mendoza & Wichman, 1978; Straub, 1989). Schädlich, Erlacher & Schredl's (2016) findings concluded that lucid dreamers with few "distractors" performed the best showing highest improvement (18%) from pre-test to post-test when compared to the lucid dream practice group which experienced many distractions in the dream (-14% reduction), the physical practice group (9% improvement) and the control group (6% reduction). Dream experiences that were distracting participants from performing the lucid dreaming dart throwing task, were deemed as distractors, such as dream characters interfering with the scene.

2.12.4 Creativity

"I dream my painting and I paint my dream"
Vincent van Gogh (1853 – 1890)

As mentioned earlier in the chapter, sleep, particularly REM sleep and the ability to remember dreams, is associated with problem solving and creativity. (Schredl, 1995; Cai, Mednick, Harrison, Kanady & Mednick, 2009; Page & Kwiatkowski, 2003). Furthermore, a study by Zink & Pietrowsky (2013) showed that there is also a positive relationship between LDF and

creativity, thus producing similar results to Blagrove & Hartnell (1998) who were first to empirically test this relationship. While it is hard to separate whether higher DRF, a significant correlate of LDF, is solely responsible for this correlation, positive correlations between personality traits such as openness to experience, need for cognition, internal locus of control and LDF, suggest that that high LDF is likely to play an additive part to high DRF in enhancing creativity and problem solving.

2.13 Chapter 2 closing remarks

Following the description of the theoretical background of lucid dreaming and lucid dream induction techniques, the following chapters will investigate: (i) individual differences in LDF, (ii) the popular and successful combination of RT + WBT + MILD cognitive techniques and (iii) the final study chapter will investigate a novel external stimulation technique.

The individual differences in LDF study chapter will investigate individual differences in LDF through online questionnaires carried out via social media and LD interest forums, in order to achieve a high sample size. The individual differences in LDF study chapter also evaluates a variety of questionnaires used in the literature as well as new ones and its aim is to not only shed light on individual differences in LDF but to also investigate which questionnaires will be useful to be included in the subsequent two study chapters.

In terms of cognitive techniques, in the thesis, I will particularly focus on investigating the effectiveness of the RC + WBTB + MILD technique through an online two-week intervention. Based on the findings by Aspy, Delfabbro, Proeve & Mohr (2017) and Aspy (2020) who found that among different cognitive techniques and combinations the RC + WBTB + MILD performed the best, as well as past research from LaBerge's lab group, it is becoming increasingly likely that the RC + WBTB + MILD technique combination is the best cognitive

LD induction technique. As such, Chapter 4 will report a constructive replication of Aspy et al's (2017) two-week protocol, with several additions such as providing an audio guided relaxation script followed by an audio-guided form of the MILD technique and the addition of dream sign work (Levitan, 1992). Moreover, the LDF correlates that have been found to be significant in Chapter 3 will also be investigated in Chapter 4, to ascertain their impact on LD induction success.

The final study chapter is a sleep lab study that investigates a novel technique of inducing LDs through external auditory stimulation. This technique, titled Individualised Auditory Stimulation (IAS), aims to present an auditory stimulus during REM as close to each individual AT as possible. To achieve this, ML algorithms will be trained to predict individual ATs. The response to the auditory stimulus is trained in a method akin to TLR used by Carr et al. (2020). A key difference in our TLR protocol is that in pre-training, the auditory stimulus used will be a text-to-speech voice that will not only inform participants that they are dreaming, but before doing so, it will call out participants' first name in an attempt to enhance frontal cortex activation, a requisite for LD induction (Dresler et al., 2012; Voss et al., 2009) based on findings from sleep auditory processing studies provided in this chapter (e.g., Vallat et al., 2017; Ruby et al., 2013; Perrin, García-Larrea, Mauguière & Bastuji, 1999; Eichenlaub, Bertrand, Morlet & Ruby, 2014; Portas et al., 2000).

Chapter 3

Individual Differences in lucid dream frequency studies

3.1 Introduction

LaBerge (1985), the 'father' of lucid dreaming research stated that lucid dreaming (LD) is within the capability of all individuals. While this statement may be over-exaggerated, the fact remains that studies show that there is a significant portion of the population who have experienced LDs (Saunders et al., 2016) and that LD is a trainable phenomenon (Stumbrys et al., 2012). Firstly, this chapter will attempt to shed light into lucid dream frequency (LDF) correlates by attempting to replicate several past findings as well as look into new possible correlates. Secondly, this chapter will look into LD induction technique practises to investigate how often and what techniques are being used. This investigation is carried out through online questionnaires advertised in popular LD forums/websites.

As outlined in Chapter 2, Saunders et al's (2016) LD prevalence and frequency meta-analysis, which included 34 studies and spanned five decades worth of research (N = 24,282 participants), demonstrated that more than half of the population has experienced LDs at least once in their life-time. Moreover, about 23% of the test population reported a LDF of about one LD per month or more often (Saunders et al., 2016). The psychophysiological components that make someone more or less likely to have experienced LDs or how often they experience them are still under investigation. Past research has shown that there exists a continuity of cognitive and metacognitive abilities from wake to sleep, with higher cognitive/metacognitive abilities during wake being correlated with higher LDF (e.g., Blagrove & Harnell, 2000; Stumbrys, Elracher & Malinowski; Blagrove, Bell & Wilkinson, 2010). A cognitive correlate

of LDF that consistently ranks as one of the highest in the literature is dream recall frequency (DRF). As outlined in Chapter 2, DRF has been linked with distinct neurobiological differences that also favour LD occurrence, such as an increase in mPFC white-matter density and increased TPJ and mPFC activity (Eichenlaub et al., 2014; Vallat, Eichenlaub & Ruby, 2018). DRF is usually assessed with the following question: "How often have you recalled your dreams recently (in the past several months)?" and respondents answer on a 7-point Likert scale ranging from "Never" to "Almost every morning". However, such conceptualisation of DRF does not capture how much of the dream content one can usually recall. For example, dream memory recall can be quite fragmented, such that fleeting dream images are only recalled, while other times, dream memory recall can be highly detailed or almost complete. As such, in addition to the traditional DRF question, the present study will investigate dream recall completeness (DRC) and how it correlates with LDF.

When it comes to metacognitive correlates of LDF, higher levels of mindfulness have been associated with higher LDF as well as higher dream control abilities (Stumbrys, Erlacher & Malinowski, 2015; Stumbrys & Erlacher, 2017; Baird, Riedner, Boly, Davidson & Tononi, 2019). Past studies have only used the Freiburg Mindfulness Inventory (FMI; Walach, Buchheld, Buttenmuller, Kleinknecht & Schmidt, 2006), a unidimensional questionnaire of mindfulness to investigate how mindfulness correlates with LDF (e.g., Stumbrys, Erlacher & Malinowski, 2015; Stumbrys & Erlacher, 2017). Hence, the present study aims to investigate different aspects of mindfulness and how they relate to LDF. To investigate different aspects of mindfulness, the Five Facets of Mindfulness questionnaire were utilised (FFMQ; Bauer et al., 2006). The FFMQ (Bauer et al., 2006) splits mindfulness into five factors; "Observing" (i.e., noticing or attending to internal feelings and thoughts and external simulation); "Describing" (i.e, ability to describe feelings, thoughts and experiences with words); "Acting

with awareness" (i.e., attending to the present); "Non-judging of Inner Experience" (i.e., assuming a non-evaluative stance toward internal thoughts and feelings); and "Non-reactivity to Inner Experience" (i.e., letting emotions and thoughts pass by, without being affected by them).

As mentioned, not only do a significant amount of the population report having experienced LDs but also, LD is a trainable phenomenon which can be increased in frequency through a variety of techniques, ranging from cognitive to external stimulation and pharmaceutical approaches (Stumbrys et al., 2012). Multiple social media groups and websites are dedicated to discussing the topic of LDs and teaching LD techniques. They are based not only on the findings of the scientific literature (e.g., the MILD technique and reality checks), but also on methods that have been derived through self-experimentation. An example of such a technique is ADA, short for All Day Awareness, a new mindfulness-inspired technique where practitioners have to practise mindfulness meditation, remaining mindful throughout the day, preventing automatic actions and thoughts (even for mundane things) as much as possible. This "mindfulness on steroids" technique has not been empirically tested in the literature before and it is unknown when it spread online. A search of the term "All day awareness" on Google Trends reveals that the term was first searched in 2007 with a steady increase in search popularity from 2008 onwards (appendix 3.2). A further search revealed that continuous mindful awareness as an LD induction practise was first described in LD forums in 2008. Thus, the technique seems to have appeared as a result of earlier research into the relationship between meditation and LDF (Gackenbach & Bosveld, 1991; Hunt, 1989; Hunt & Ogilvie, 1988), but before mindfulness as a state or as meditation technique and its association with LDF was empirically tested (Rider, 2012; Stumbrys, Erlacher & Malinowski, 2015). However, since mindfulness belongs in the umbrella of meditation techniques, it is uncertain whether

research was inspired from online LD forums and websites or whether investigating mindfulness was a logical step due to the nature of mindfulness and its exploding popularity in the recent years. An LD induction technique that was clearly borne out of the online community is the Senses-Initiated Lucid Dream (SSILD) technique. SSILD is a WILD technique that was first developed and posted in a Chinese LD forum by Zhang in 2013 (Zhang, 2013) and was empirically tested for the first time much later by Aspy (2020) who demonstrated that MILD and SSILD are similarly effective for inducing lucid dreams. It is thus fascinating how the relationship between the online LD community and formal LD research informs one another in the search for effective LD induction techniques. Consequently, in an attempt to quantify this relationship, this chapter will also investigate what LD induction techniques online LD forum/website users are currently using and which ones they consider most successful at inducing LDs.

Finally, this chapter will look into the association between retrospective and prospective memory ability and LDF. It is postulated by several authors that LD induction techniques such as the Mnemonic Induced Lucid Dream (MILD) technique rely heavily on prospective memory, particularly for the 'Intention' part of the technique (Baird, Mota-Rolim & Dresler, 2020). Specifically, this is where practitioners set an intention to remember that they are dreaming by repeating a mantra such as "Next time I am dreaming I will remember that I am dreaming" (Stumbrys et al., 2012). Despite claims for the role of prospective memory in the MILD technique, to date prospective or retrospective memory ability has not been investigated in this context.

Taking into account the previous findings and logical next-steps outlined above, the present study makes the following hypotheses:

1) DRF, Need For Cognition (NFC) and lucid dreaming practise frequency will be positively correlated with LDF, replicating past results.
2) Higher LDF will be associated with the ability to recall dreams in higher detail more often and to have less fragmented dream recall memories.
3) LDF will be positively correlated with higher amount of dream memory recall.
4) PRMQ's prospective memory metrics (short/long-term memory and self/environmentally cued) will be negatively correlated with LDF.
5) FFMQ factors Observe, Describe, Acting with Awareness and Non-react will be positively correlated with LDF, whilst factor Non-Judge will not be correlated with LDF.

3.2 Methods

3.2.1 Participants

Participants were pooled from 3 surveys (appendix 3.1) that were sent out in online LD forums (mostly from subreddit /LucidDreaming) and through the university's Psy-Vol study participation system. In total, 1079 participants completed the questionnaires. 244 were females. Mean age was 24.34 with ages ranging from 13 to 72.

3.2.2 Materials

3.2.2.1 Demographics questionnaires

Demographics questions were age, sex, gender and occupation and country.

3.2.2.2 Sleep quality questionnaire (PSQI)

The Pittsburgh Sleep Quality Index (PSQI), a self-report questionnaire which assesses sleep quality was used (Buysse et al., 1989). PSQI measures sleep quality in 19 questions which compose 7 factors; subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medications and daytime dysfunction.

3.2.2.3 Five-Facets of Mindfulness (FFMQ)

The FFMQ (Baer, Smith, Hopkins, Krietemeyer & Toney, 2006) questionnaire splits mindfulness into five factors: “Observing” (i.e., noticing or attending to internal feelings and thoughts and external simulation); “Describing” (i.e, ability to describe feelings, thoughts and experiences with words); “Acting with awareness” (i.e., attending to the present); “Non-judging of Inner Experience” (i.e., assuming a non-evaluative stance toward internal thoughts and feelings); and “Non-reactivity to Inner Experience” (i.e., letting emotions and thoughts pass by, without being affected by them).

3.2.2.4 Prospective and Retrospective Mistake Questionnaire (PRMQ)

The PRMQ (Smith, Della Sala, Logie & Maylor, 2000) was given to participants. PRMQ assesses the frequency of retrospective and prospective memory mistakes. It further categorises retrospective and prospective mistakes into long vs short term memory retrospective/prospective memory mistakes that are either self or environmentally cued. For example, a retrospective, short-term memory, self-cued item is “Do you mislay something that

you have just put down, like a magazine or glasses?" and a prospective, short-term environmentally cued item is " Do you intend to take something with you, before leaving a room or going out, but minutes later leave it behind, even though it's there in front of you?".

3.2.2.5 Need For Cognition (NFC)

The NFC (Cacioppo & Petty, 1982) measures "the tendency for an individual to engage in and enjoy thinking" (Cacioppo & Petty, 1982, p. 116). Examples of questions included in NFC are "Learning new ways to think doesn't excite me very much" and "I find satisfaction in deliberating hard and for long hours"

3.2.2.6 Dreaming questionnaires

Dream behaviour was measured using 4 questionnaires: Dream Recall Frequency, Lucid Dream Frequency, the Mannheim Dream Questionnaire and the Lucid Dream Skills questionnaire. These are described below:

Participants were asked to estimate how often they are able to recall having dreamt with the Dream Recall Frequency (DRF) question which measures DRF through a 7-point response scale (coded as 1 = never, 2 = less than once a month, 3 = about once a month, 4 = about 2 to 3 times a month, 5 = about once a week, 6 = several times a week, 7 = almost every morning). To elucidate how complete their dream memory had been in the past several months, a modified question from Aspy et al. (2017) was also used. Participants were asked to estimate a percentage of how complete their dream memory was in the days where they had woken up

remembering that they had dreamt the night before (in the past several months). The choices were as follows:

- Fragmentary (F) - “You recall some content (such as a single scene or an isolated image). But not enough to provide any “flow” in the narrative. There are no transitions from one scene or event to the next”;
- Partial (P) - “You recall enough content for there to be some “flow” in the narrative from one scene or event to the next. However, you’re pretty sure that most of the dream has been forgotten”;
- Majority (M) - “You recall a substantial amount and you’re pretty sure you can recall at least half of the dream. However, there are frustrating gaps indicating that a significant amount is still missing”;
- Whole (W) - “Fairly complete recall of the dream without any frustrating gaps in your memory of what happened (although the beginning of the dream and some details might still be missing)”.

The above categories had a “constant sum” format, where the total percentage given in the categories had to amount to 100%.

Lucid Dream Frequency (LDF) measures how often one has a lucid dream and was assessed using an eight-point rating scale (“How often do you experience so-called lucid dreams?”: 0 = never, 1 = less than once a year, 2 = About once a year, 3 = about two to four times a year, 4 = about once a month, 5 = two to three times a month, 6 = about once a week, 7 = several times a week). The following definition for lucid dreams was given: “In a lucid dream, one is aware that one is dreaming during the dream. Thus, it is possible to wake up deliberately, or to

influence the action of the dream actively, or to observe the course of the dream passively." Participants who chose any option other than "Never" in the LDF question were also asked to indicate (or estimate) how many lucid dreams they had experienced in total, and to indicate (or estimate) their lucid dream age onset (i.e., how old they were when they had their first lucid dream).

The Mannheim Dream Questionnaire (MADRE; Schredl, 2014) asks questions relating to different aspects of dreaming. It includes the DRF and LDF mentioned questions above, dream affect questions, questions relating to nightmares such as current and childhood nightmare frequency and distress, and questions relating to attitudes about dreams.

The Lucid Dream Skills questionnaire (LUSK; Schredl, Rieger, Goritz, 2018), is a questionnaire measuring inter-individual differences in lucid dreaming skills. LUSK is a 10-item questionnaire which enquires participants to estimate the frequency of awareness and control skills exhibited in lucid dreams, using a 5-point response scale (0 = In none, 1 = In a quarter, 2 = In half, 3 = In three quarters, 4 = In all), over two factors: Awareness/Perception (e.g., " …were you able to keep your awareness for a satisfying period of time?") and Control (e.g., " … were you able to deliberately shape your environment, change landscapes/surroundings, let persons/characters appear or disappear?").

3.2.2.7 LD technique practice questionnaires

To ascertain various aspects the practice of previous lucid dream techniques, participants were asked if they had ever tried to have lucid dreams by learning and practising a lucid dream technique and how often they had practised such a technique in the past several months (0 =

Never, 1 = Less than once a month, 2 = About once a month, 3 = Two or three times a month, 4 = About once a week, 5 = Several times a week, 6 = Almost every morning).

A 5-point scale was also used to elucidate how many of their lucid dreams happened spontaneously versus induced through a technique: 1 = "All my lucid dreams occurred spontaneously (without using any techniques)"; 2 = "Most of my lucid dreams were spontaneous, but some lucid dreams were deliberately induced (by using some lucid dream induction technique)"; 3 = "About half of my lucid dreams were spontaneous and the other half were deliberately induced"; 4 = "Most of my lucid dreams were deliberately induced, but some lucid dreams also occurred spontaneously"; 5 = "All my lucid dreams were deliberately induced").

To look more closely into what techniques participants had practised before, they were provided with a descriptor list of popular lucid dream induction techniques (from the scientific literature and online sources) to choose from (MILD: Mnemonic Induced Lucid Dream; WILD: Wake Initiated Lucid Dream; WBTB: Wake Back to Bed; VILD: Visual Incubation of Lucid Dreams; CAT: Cycle Adjustment Technique; RC: Reality Checks; ADA: All Day Awareness; Autosuggestion; Drug Applications; Binaural beats and other sounds; Stimuli devices; Other).

A question then asked which lucid dream induction technique (or combination of techniques) that yielded the best results (had at least one lucid dream with it). Participants were then asked how often participants practised their most successful induction technique in the past several months (1 = "Almost every morning", 2 = "Several times a week", 3 = "About once a week", 4= "About two to three times a month", 5= "About once a month", 6 = "Less than once a month"). Subsequently, participants were asked to estimate how many times in total they had practised their most successful induction technique by explicitly stating an estimated number. Finally, they were asked to estimate

out of all their attempts with their most successful technique how successful their most successful method has been (expressed in success rate %).

3.3 Results

3.3.1 Demographics

Overall, the surveys included 1015 participants from 73 countries. The five countries with the most participants were the United States (42.8%), United Kingdom (10.6%), Canada (6.6%), Germany (5.8%) and Australia (4.2%).

3.3.2 Lucid dreaming frequency, dream recall frequency and completeness, effects of gender on dream attitudes/beliefs and dream types.

In Table 3.1, the frequencies of the lucid dreaming frequency scale are represented. 86.6% of the participants reported that they had experienced a lucid dream at least once in their lifetime. The majority of the participants who have experienced lucid dreams at least once, experience them infrequently, as about 35.9% are frequent lucid dreamers (frequency ≥ than once per month), as defined by Snyder and Gackenbach (1988). The average lucid dreaming frequency (LDF) was 3.28 ± 2.19 and the most frequent LDF response was that participants experience LDs about two to four times a year. There was a significant sex difference when it came to LDF. Women (N = 244) reported a higher LDF than men, $U = 72677.50$, $Z = -4.157$, $p < .001$. Women also exhibited higher DRF, $U = 14158$, $Z = -3.028$, $p = .002$, dream attitude, $U = 13031$, $Z = -3.227$, $p = .001$, dream sharing frequency, $U = 11590$, $Z = -4.805$, $p < .001$, being more affected by dreams in their daytime, $U = 13357.5$, $Z = -3.042$, $p = .002$ and having a higher frequency of creative and problem-solving dreams, $U = 14254$, $Z = -2.037$, $p = .042$ and $U = 13111.5$, $Z = -3.206$, $p = .001$, respectively. Thus the gender DRF differences may be explained

by the fact that women exhibit different attitudes towards dreams, more creative and problem solving dreams and they share their dreams with others

Table 3.1 Lucid dreaming frequency (LDF) question answered by 1010 participants. The LDF questionnaire asks how often participants experience lucid dreams on a 8-point Likert scale. Frequency column displays absolute number of responses and Relative frequency (%) column displays percentage of the sample who chose each response.

Lucid dream frequency	***Frequency***	**Relative frequency (%)**
Never	135	13.4
Less than once a year	135	13.4
About once a year	91	9
About two to four times a year	206	20.4
About once a month	129	12.8
About two to three times a month	116	11.5
About once a week	100	9.9
Several times a week	98	9.7
Total	**N = 1010**	

As demonstrated in graph 3.1 below, for dream recall frequency (DRF), on average participants reported that they recall dreams several times a week (M = 5.79, SD = 1.19).

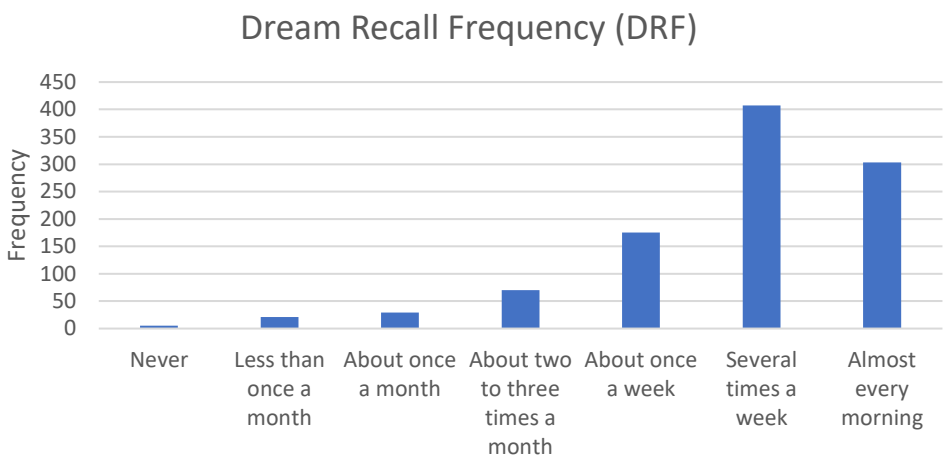

Figure 3.1. Dream recall frequency. Responses were numbered as follows: 1 = Never, 2 = Less than once a month, 3 = About once a month, 4 = About two to three times a month, 5 = About once a week, 6 = Several times a week, 7 = Almost every morning.

Somers' d was run to determine the association between LDF and DRF amongst 1010 participants (figure 3.2). There was a moderate, positive correlation between LDF and DRF, which was statistically significant (d = .450, p < .001).

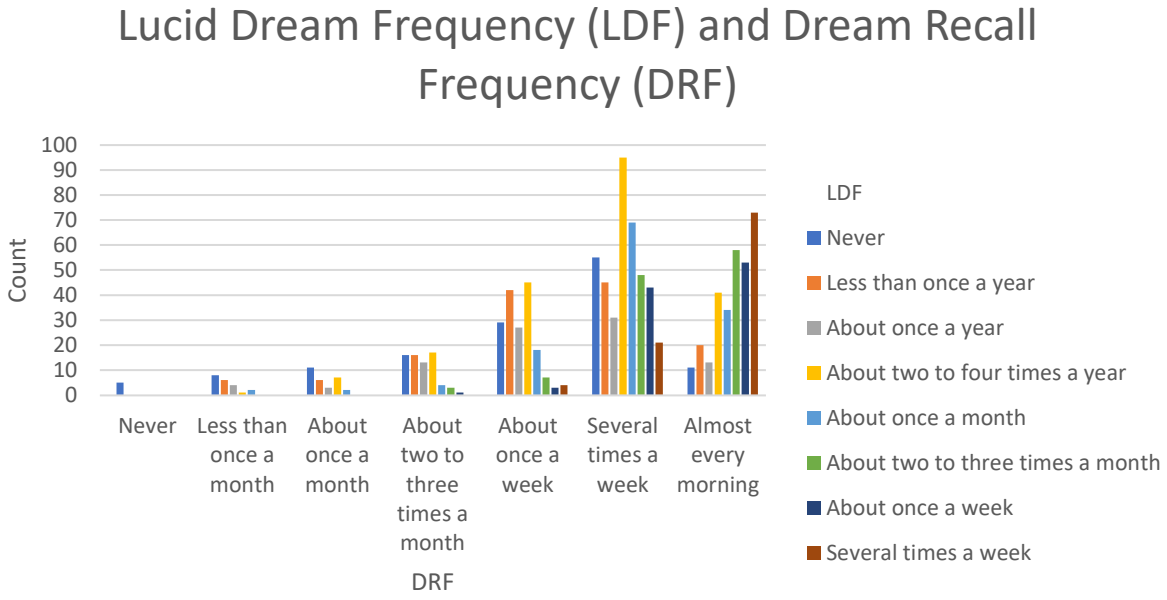

Figure 3.2. This figure shows the participant responses to the Lucid Dream Frequency (LDF) and Dream Recall Frequency (DRF) questions. As can be seen, participants who chose higher DRF Likert-scale responses were more likely to choose a higher LDF response and vice versa.

A Spearman's rank-order correlation was run to assess the relationship between LDF and percentage of experienced frequency of different types of dream recall completeness (DRC; fragmentary, partial, majority and complete). There was a small negative correlation between percentage of fragmentary dream memory recall and LDF, $r_s(886) = -.302$, $p < .001$.There was a small negative correlation with percentage of partial dream recall memory and LDF, $r_s(886) = -.118$, $p < .001$, There was a small positive correlation between percentage of majority dream memory recall and LDF, $r_s(886) = .306$, $p < .001$.. Finally, there was a medium positive correlation between percentage of whole dream memory recall and LDF, $r_s(886) = .284$, $p < .001$. These results demonstrate that the more compete the dream memory recall is, the higher LDF is. This suggests that not only the ability to recall having dreamt (DRF) but also the ability to recall dreams in more detail is impacts LDF positively.

3.3.3 Lucid dream frequency, lucid dream skills, cognitive/metacognitive correlates and lucid dream induction technique practises

3.3.3.1 LDF, FFMQ and LUSK questionnaire

Table 3.2 Table showcasing significant correlations between LDF and FFMQ and LUSK factors

Significant LDF correlations	**N**	**Spearman rank (rs)**	**Interpretation**
FFMQ Observe	544	.205**	Small
FFMQ Describe	544	.137**	Small
FFMQ Awareness	544	.143**	Small
Total LUSK score	1045	.640**	Large
LUSK awareness control	1045	.621**	Large
LUSK control	1045	.538**	Large

*p < .05. **p < .01

A Spearman's rank-order correlation was run to assess the relationship between LDF and mindfulness using full version of the Five Facets of Mindfulness (FFMQ). In total, 554 participants completed FFMQ. There were significant correlations found between LDF and all factors except the Nonjudge factor. Specifically, there were small positive correlations between LDF and Observe factor, $r_s(554) = .205$, $p < .001$ and Describe, $r_s(554) = .137$, $p < .001$, Awareness, $r_s(475) = .143$, $p < .001$, Non-reactiveness , $r_s(554) = .110$, $p < .001$. These results show that the ability to direct attention to the present moment through observation, being able to label inner experience having inner awareness of our actions and being actively detached from negative thoughts/emotions is positively correlated with LDF, whilst being non-judgmental of inner experience (i.e., self-acceptance and unconditional empathy for oneself and others) is not a correlate for LDF.

3.3.3.2 LDF and LUSK's total score, dream awareness and dream control

A Spearman's rank-order correlation was run to assess the relationship between LDF and lucid dream skills assessed by the LUSK questionnaire. There were significant large positive correlations with LDF and total LUSK score, $r_s(1045) = .610$, $p < .001$, LUSK's dream awareness score, $r_s(1045) = .621$, $p < .001$ and LUSK's dream control score, $r_s(1045) = .538$, $p < .001$. These results demonstrate that higher occurrence of LDs is associated with higher LD skills, likely due to repeated exposure to them

3.3.3.3 LUSK total score and FFMQ

A Spearman's rank-order correlation was run to assess the relationship between mindfulness and lucid dream skills. Only two of the FFMQ's factors were found to be significantly

correlated with total LUSK score. Specifically, Observe and Describe factors were found to be weakly positively correlated with total LUSK score, $r_s(441) = .244$, $p < .001$ and $r_s(441) = .129$, $p < .001$, respectively. Similarly, to Stumbrys & Erlacher (2017), these results show a link between mindfulness and lucid dream skills, such as the ability to control aspects of the dream narrative.

Specifically, FFMQ's Observe and Describe factors were found to be weakly positively correlated with LUSK's dream awareness score, $r_s(441) = .258$, $p < .001$ and $r_s(441) = .140$, $p = .003$, respectively. FFMQ's Observe and Describe factors were also found to be weakly positively correlated with LUSK's dream control score, $r_s(441) = .209$, $p < .001$ and $r_s(441) = .124$, $p = .009$, respectively. This suggests that the ability of having a mindful sensory awareness which allows one to see, feel and perceive the internal and external world in the present moment, as well as the ability to label ones conscious experience, affects the frequency with which higher lucid dream awareness and control skills are exhibited.

3.3.3.4 LDF and PRMQ

A total of 1079 participants completed the Prospective and Retrospective Mistake Questionnaire (PRMQ). A Spearman's rank-order correlation was run to assess the relationship between LDF and the frequency of retrospective and retrospective memory mistakes. There were significant small negative correlations between LDF and the total frequency of retrospective memory mistakes score, $r_s(1079) = -.124$, $p < .001$, and between LDF and the total frequency of prospective memory mistakes score, $r_s(1079) = -.105$, $p < .001$.

The highest correlated factor of retrospective memory with LDF was the frequency of short-term retrospective memory mistakes that are environmentally cued, $r_s(1079) = -.240$, $p < .001$, followed by the frequency of long-term retrospective memory mistakes that are self-cued, $r_s(1079) = -.131$, $p < .001$, the frequency of long-term retrospective memory mistakes that are environmentally cued, $r_s(1079) = -.116$, $p < .001$ and the frequency of short-term retrospective memory mistakes that are self-cued, $r_s(1079) = -.098$, $p < .001$.

The highest correlated factor of prospective memory with LDF was the frequency of long-term prospective memory mistakes that are environmentally cued, $r_s(1079) = -.136$, $p < .001$, followed by the frequency of short-term prospective memory mistakes that are self-cued, $r_s(1079) = -.113$, $p < .001$, the frequency of short-term prospective memory mistakes that are environmentally cued, $r_s(1079) = -.086$, $p < .001$ and the frequency of long-term-term prospective memory mistakes that are self-cued, $r_s(1079) = -.083$, $p < .001$. These results suggest that both higher prospective and retrospective memory ability are involved in realising that one is dreaming. Conceivably, perspective memory ability is more involved when practising certain cognitive techniques that employ prospective memory such as the MILD technique, where one sets an intention to remember that one is dreaming (Baird, Mota-Rolim & Dresler, 2020; Stumbrys et al., 2012), whilst retrospective memory ability allows one to realise or spot incongruences between waking life and the dream scenario. Furthermore, the overall frequency of retrospective memory mistakes was negatively correlated with DRF, $r_s(1010) = -.122$, $p < .001$, leaving the possibility open that LDs in those with low LDF may occur in higher numbers than reported but are perhaps not successfully recalled.

3.3.3.5 LDF and Need for Cognition (NFC)

A Spearman's rank-order correlation was run to assess the relationship between LDF and NFC amongst 406 participants. NFC score was significantly correlated with LDF. Results indicated a small positive correlation between LDF and NFC, $r_s(406) = .118$, p = .017, which indicates that higher cognitive complexity and flexibility is correlated with higher LDF, replicating past NFC and LDF association findings by Blagrove & Harnell (2000).

3.3.3.6 LDF and sleep quality measures

Somers' d was run to determine the association between LDF and PSQI questions amongst 396 participants. There was a small, significant, positive correlation between LDF and the frequency in which participants had trouble sleeping because of waking up in the middle of the night or early morning, d = .086, p = .022. In addition, there was a small, significantly positive correlation between LDF and the frequency in which participants had trouble sleeping because they had to get up to use the bathroom, d = .130, p = .003. These results suggest that these intra-night awakenings might subsequently lead to an increase cortical activation that persists whilst entering REM sleep after going back to sleep (Smith & Blagrove, 2015). There was small significant negative correlation between LDF and problem severity of not being able to keep up the enthusiasm to get things done, which was statistically significant, d = -.154, p <.001. Finally, there was a significant small negative correlation with perceived sleep quality rating, d = -.118, p = .023.

3.3.3.7 LDF and LD technique practice frequency

Somers' d was run to determine the association between LDF and LD induction technique practise frequency amongst 1000 respondents (figure 3.3). There was a small, positive correlation between LDF and LD induction technique practise frequency, which was statistically significant, d = .220, p < .001). This result replicates previous research showcasing that LDs are a trainable phenomenon (Stumbrys et al., 2012).

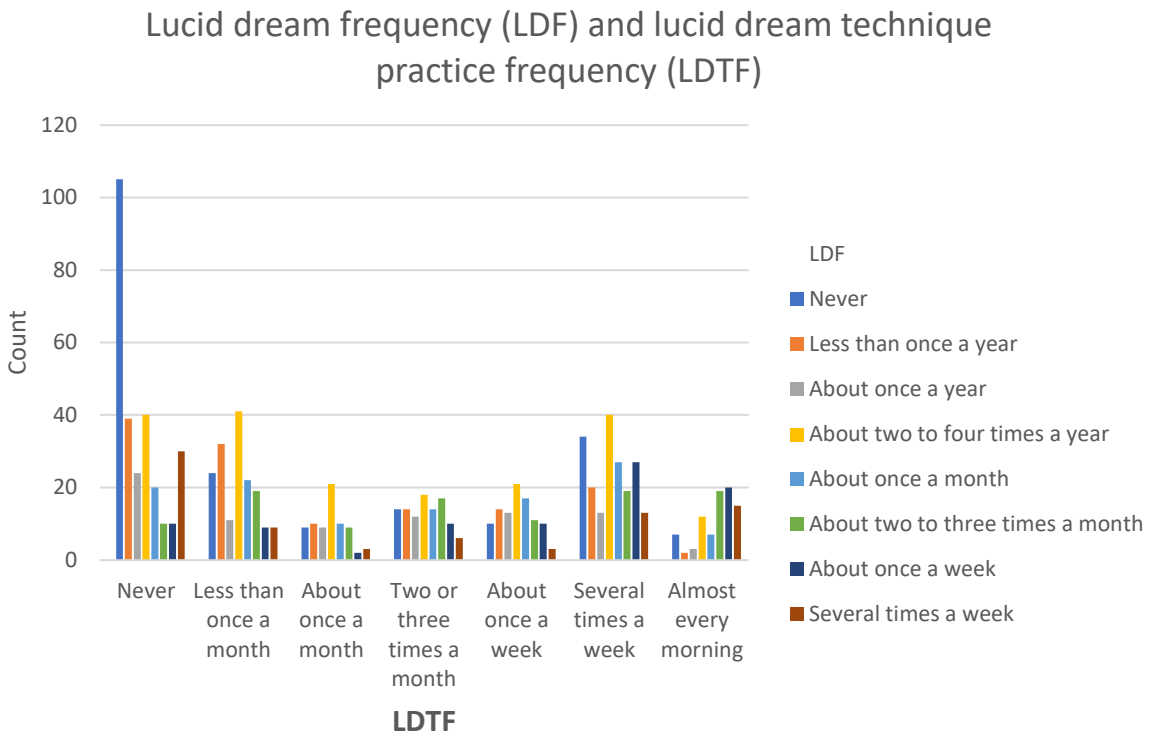

Figure 3.3 Graph showing responses lucid dream frequency (LDF) and lucid dream technique practice frequency (LDTF) responses

Participants were then split into the five categories of spontaneous vs deliberate (i.e., induced through an LD induction technique) LD occurrence (graph 3.4).

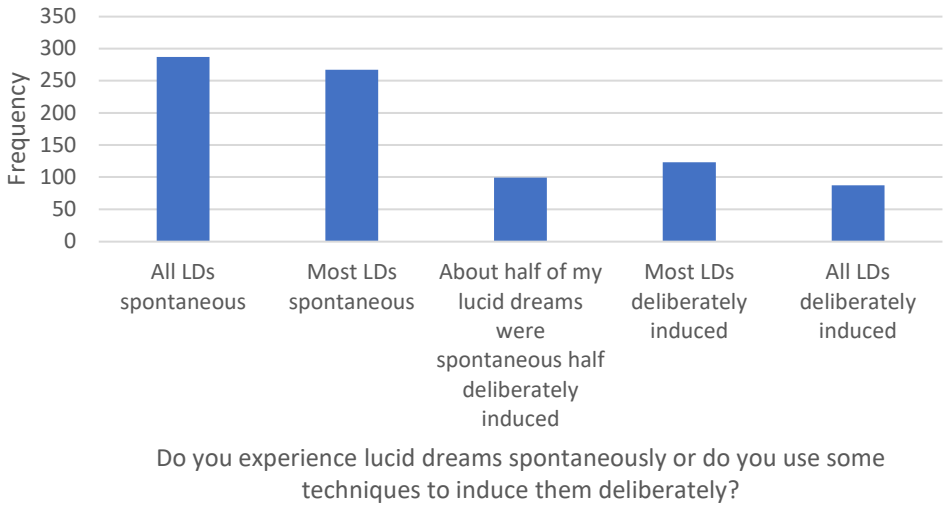

Figure 3.4 This graph displays the number of participant responses to the question of whether they experience lucid dreams spontaneously or whether they use some techniques to induce them deliberately.

Most responded that all their LDs happened spontaneously (N = 287), closely followed by the response that most LDs they've experienced were spontaneous but that some were deliberately induced through LD induction techniques (N = 264). These results demonstrate that the vast majority of the people questioned had experienced lucid dreams spontaneously at some point of their lives and only a small minority (N = 87) experienced LDs only through LD induction techniques.

Participants were then split into the five categories of spontaneous vs deliberate LD occurrence to look into group differences in LDF (graph 3.5).

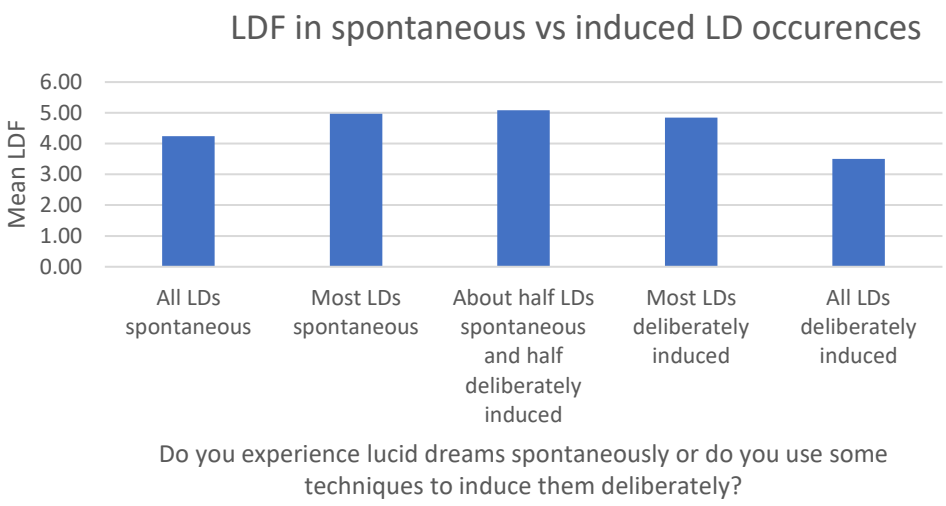

Figure 3.5 This graph demonstrates the difference in LDF in five different groups depending on spontaneous vs induced LD occurrences. The graph data has been controlled for lucid dream technique practise frequency.

An ANCOVA was run to determine LDF differences between spontaneous vs induced LD occurrences groups after controlling for LD technique practice frequency. After adjustment for pre-intervention cholesterol concentration, there was a statistically significant difference between the spontaneous vs deliberate LD groups, $F(4, 326) = 5.091$, $p < .001$, partial $\eta 2 = .059$. Post hoc analysis was performed with a Sidak adjustment. The 'All LDs deliberately induced' group exhibited a statistically significantly lower LDF than all other groups ($p < .05$) with the exception of the 'All LDs spontaneous' group ($p > .05$). These results show that whilst the 'All LDs deliberately induced' group has one of the lowest LDF, alongside the 'All LDs spontaneous' group, it is still possible to induce LDs through performing LD induction techniques even in persons who have never experienced any spontaneous LDs in their lifetime.

3.3.3.8 LD induction technique practises questionnaires

Overall, 879 participants completed the lucid dream technique types practised questionnaire. The most picked technique to have practised was reality checks with 544 participants having

practised it in their lifetime, followed by the WBTB, WILD, MILD and ADA. See table 3.3 below for detailed breakdown.

Table 3.3. Table showcasing which LD induction techniques participants had practised in their lifetime. Frequency column displays the number of multiple-choice responses and relative frequency column displays the percentage from the total sample size which chose having practised each technique.

LD induction techniques	**Frequency**	**Relative frequency (%)**
Reality Checks	616	63
Wake Back to Bed (WBTB)	494	50.5
Wake Induced Lucid Dream (WILD)	456	46.6
Mnemonic Induced Lucid Dream (MILD)	411	42
All Day Awareness (ADA)	271	27.7
Autosuggestion	205	21
Binaural Beats	194	19.8
Other	102	10.4
Visual Incubation of Lucid Dreams (VILD)	93	9.5
Drug application	88	9
Dream Journaling	59	6
Cycle Adjustment Technique (CAT)	54	5.5
Stimuli devices	38	3.9
Total	**N = 978**	

614 participants who have had at least one lucid dream that was induced by practising an LD technique or a combination of LD techniques picked their best performing technique(s). The most picked best performing technique was 'reality testing' (N = 91). The top fifteen best performing techniques according to the survey are displayed in table below.

Table 3.4 Table shows the top 15 most successful techniques or combination of techniques that were considered the most successful at inducing LDs. The frequency column number references to the total number of participants who chose each technique (or combination of techniques).

Top 15 most successfully LD induction techniques	***Frequency***
Reality Testing (RT)	91
WBTB	78
Wake Induced Lucid Dream (WILD)	43
RT + Wake Back to Bed (WBTB)	41
Other	39
Mnemonic Induced Lucid Dream (MILD)	30
WBTB + WILD	23
WBTB + MILD	15
ADA + RT	15
ADA	14
RT + WBTB + WILD	11
Autosuggestion	10
Dream Journaling	8

RT + MILD	7
MILD + WILD	7
Total	**$N_{(total)}$ = 614**

3.4 Discussion

The purpose of this chapter was to gain a better understanding of individual differences in lucid dream frequency (LDF) and investigate LD induction technique practises of online LD communities.

One of the hypotheses that LDF would be positively correlated with DRF was confirmed by results where people who had higher LDF also exhibited higher DRF, a pattern that is consistent with a myriad of previous literature findings (Wolpin, Marston, Randolph & Clothier, 1992; Schredl & Erlacher, 2004; 2011; Hess, Schredl & Goritz, 2016). Besides looking into DRF correlation with LDF, for the first time in the literature (to my knowledge), the relationship between the dream memory completeness (DRC) and LDF was investigated. As hypothesised, respondents who exhibit high LDF, report a greater number of recalled dreams that are remembered in higher detail whilst fragmented memory dreams consisted a much less proportion of recalled dreams. The connection between remembering having dreamt, as well as remembering dreams in more detail suggests that a common neurobiological factor is at play, particularly in the frontotemporal region. Past research has shown that higher LDF is associated with higher greater grey matter density in prefrontal brain areas (Filevich, Dresler, Brick, & Kuhn, 2015; Stumbrys, Erlacher, & Schredl, 2013). In addition, the activity in prefrontal and temporoparietal cortices has been shown to be more activated and exhibit a higher frequency (gamma band frequency) when people experience lucid dreams than when

they have ‘normal’ dreams (Dresler et al., 2012; Voss & Voss, 2014). Likewise, higher DRF has been associated with increased medial prefrontal cortex (mPFC) white matter and an increase in activity in mPFC and temporoparietal junction (TPJ) in both wakefulness and sleep when compared to subjects with lower DRFs (Vallat, Eichenlaub & Ruby, 2018; Eichenlaub et al., 2014). The effect of mPFC in promoting higher LDF and DRF is also supported by the finding of the present study that participants who display depressive-like symptoms, as ascertained by the PSQI question “How much of a problem has it been for you to keep enough enthusiasm to get things done?”, exhibit lower LDF and DRF. Past research has repeatedly demonstrated that the frontal cortex activity is negatively affected in depression (Lai, 2019), leading to a decline in executive functioning, drive and motivation. Furthermore, it is reasonable to propose that the same neurobiological differences between high DRF and low DRF are also applicable in those who are able to not only recall having dreamt often but also exhibit higher DRC.

When it comes to the gender differences investigated in the present study, Women were found to have higher LDF than men, a finding that is consistent with previous findings of studies looking into gender differences in LDF (Bulkeley, 2014). Interestingly, the results of the current study indicate that these gender differences in LDF may be related to several other factors: that women have higher DRF; that they put dreams more into the forefront of their lives by writing down their dreams and sharing their dreams with others more frequently; by having a more positive attitude towards dreams; and by having more creative and problem solving dreams than males. Thus, these gender specific dream attitudes may be the driving force behind the gender differences that were found in this study. Evidence to this supposition is the finding that when controlling for dream sharing and dream recording these gender differences disappear. It is important to note that gender specific differences in dream attitudes has been found in past to also drive DRF differences between the sexes (Hess, Schredl &

Goritz, 2016; Schredl, 2002). Thus, all these findings showcase the importance of increasing LDF through activities and habits that bring dream consciousness into wakeful awareness.

One of the study's aims was to look more in depth into the association of mindfulness and LDF. Previous studies by Stumbrys, Erlacher & Malinowski (2015) and Stumbrys & Erlacher (2016) showed a positive correlation between mindfulness and LDF. Both papers had used Freiburg Mindfulness Inventory (FMI; Walach, Buchheld, Buttenmullerm, Kleinknecht & Schmidt, 2006), a questionnaire that provides an overall mindfulness score as well as splitting mindfulness into two factors: "Presence" and "Acceptance". The use of Five Facets of Mindfulness (FFMQ; Baer et al., 2006), a questionnaire which splits mindfulness into five factors, "Observe" , "Describe", "Awareness", "Non-Judge" and "Non-React", was sought to examine this behaviour in more depth and look more explicitly into which aspects of mindfulness correlate with LDF. All but one FFMQ factor, Non-judge, was positively associated with LDF. The results of the current study are thus consistent with the claim that there exists a continuity of metacognition and attention in the wake-sleep (and hence dreaming) continuum (Stumbrys, Erlacher & Malinowski, 2015). Specifically, people who are more mindful of their present experience during wake are more likely to be mindful whilst dreaming, hence more likely to notice incongruences within a dream. In addition, the present results are consistent with Stumbrys & Erlacher (2017), as I found that mindfulness is related to the extent of lucid dream skills, specifically lucid awareness and lucid dream control. This result was replicated using LUSK (Schredl, Rieger & Goritz, 2018), a more in-depth lucid dream skills questionnaire than the one used in Stumbrys & Erlacher (2017). In Stumbrys & Erlacher (2017), three lucid dream skill questions were asked whereas LUSK contains ten questions regarding lucid awareness and dream control skills (Schredl, Rieger & Goritz, 2018). Both the association of mindfulness with LDF as well as the association of mindfulness with greater

ability to exhibit lucid awareness and control skills may be linked by neurophysiologically similar phenomena between mindfulness and the LD state (Stumbrys, 2017). For example, both mindfulness and the lucid dreaming state are associated with increased prefrontal brain activity and greater grey matter density (Voss et al., 2009; Dresler et al., 2012; Filevich, Dresler, Brick, & Kuhn, 2015; Stumbrys, Erlacher, & Schredl, 2013; Creswell, Way, Eisenberger, & Lieberman, 2007; Farb et al., 2007).

Another important and novel finding was that the frequency of both retrospective and prospective memory mistakes were negatively correlated with LDF. As mentioned in the introduction, multiple techniques such as MILD (a technique first developed by LaBerge) are thought to make use of perspective memory (LaBerge and Rheingold, 1990) and this assumption has been repeated throughout the literature without being tested (e.g., Aspy et al., 2017; Stumbrys, Erlacher, Schädlich, Schredl, 2012). Based on these literature suppositions, it was expected that prospective memory measures would explain more LDF variance than retrospective measures. However, the findings of the current study do not support this. Instead, it was found that both retrospective and prospective memory ability were correlated with LDF. Moreover, the frequency of retrospective memory mistakes that are environmentally cued explained the highest LDF variance than prospective memory factors of the PRMQ. Hence, we postulate that waking prospective memory ability is likely to be more involved when practising LD induction techniques such as MILD and waking retrospective memory ability likely allows one to be able to spot dream scenario incongruences to waking life. Overall, the results suggest that waking memory ability is related to LDF, backing the continuity hypothesis between waking and dream cognition.

Additionally, NFC was found to be correlated with LDF even when controlling for LD practice frequency. This is a replicated result from Blagrove & Hartnell (2000) and are suggestive of increased metacognitive ability, such as higher Internal State awareness and self-reflectiveness (Reeves, Watson, Ramsey & Morris, 1995), in frequent lucid dreamers (Blagrove & Hartnell, 2000; Reeves, Watson, Ramsey & Morris, 1995). Moreover, higher NFC has been associated with higher fluid intelligence (Fleischhauer et al., 2010). Hence, a higher NFC is likely to increase the chance of noticing bizarre dream scenario occurrences which in turn, could lead to experiencing LDs more often (Darling, Hofmann, Moffitt & Purcell, 1993).

Taken together, the findings on mindfulness, prospective/retrospective memory and NFC indicate that higher cognitive and metacognitive abilities in waking, such as attention, memory and self-reflectiveness, are associated with higher LDF. The supposition made here is that the higher the cognitive abilities are during wakefulness, the less they either decrease whilst dreaming or, the decrease in cognitive abilities whilst dreaming is less impactful, thus leading to a higher LDF. The results add to a growing body of research showing a continuity of cognitive abilities between wakefulness and dreaming, which showcases that LDF is correlated with cognitive/meta-cognitive abilities (e.g., Kahan & LaBerge, 1994; 1996; Blagrove & Hartnell, 2000; Blagrove, Bell & Wilkinson, 2010).

When it comes to sleep quality measures and LDF associations, the sleep quality questionnaire (PSQI) indicated that midnight awakenings are correlated with higher LDF. One interpretation of these findings is that midnight awakenings act as a form of surrogate Wake Back to Bed (WBTB) technique, an effective cognitive technique that is usually coupled with other techniques such as MILD or WILD (e.g., Stumbrys & Erlacher, Schädlich & Schredl, 2012; Erlacher & Stumbrys, 2020). In WBTB the person is instructed to wake-up 2-3 hours before

their normal waking time and this brief awakening is thought to cause the person to go back to sleep with a more activated cortex, thus increasing likelihood of LD (Smith & Blagrove, 2015). Clearly, midnight awakening could provide a similar stimulus to the brain. This result is of similar nature to past research by Smith & Blagrove (2015) which showed that LDF increase was positively associated with the number of alarm snooze button presses in the morning.

Finally, the survey's investigation into LD technique practises revealed several key findings. Consistent with the literature was that practising LD techniques leads to higher LDF (Stumbrys et al., 2012). Additionally, a new finding was that LDs can be trained to be induced even in people who have reported never experiencing LDs spontaneously. Although it has to be noted that those who have experienced LDs only through practise of LD induction techniques deliberately (i.e., through practising an LD induction technique) have the lowest LDF from others who have either had only spontaneous or a mixture of spontaneous and deliberate LDs, a finding that remained consistent even after controlling for LD induction technique practise frequency. Despite this, these results further strengthen the assumption of the latest LDF meta-analysis by Saunders, Roe, Smith & Clegg (2016, p.210) that the "capacity for lucid dreaming is widespread".

Furthermore, the survey looked into LD technique popularity and respondents LD induction efficacy estimations on a variety of LD techniques. The survey revealed that top five most tried techniques were reality checks, WBTB, WILD, MILD and ADA. While ADA is placed fifth in popularity, it is placed ninth when it comes to what is considered the best performing technique (or combination of techniques). The top five techniques include techniques which have been around for a long time, such as reality testing, WBTB, WILD and MILD. In terms of future research, it would be useful to extent the current findings of effective LD techniques

by asking participants to estimate how many times they've practised their best performing technique and how effective it has been (e.g., through a success rating expressed in percentage).

3.4.1 Strengths and Limitations

One particular strength of the present study and something that was done differently from previous studies looking into the correlates of LDF and DRF was the choice of statistical test. In the past, incorrect statistical analyses have been applied in the literature when it comes to examining the relationship between lucid dream frequency (LDF) and dream recall frequency. For example, Pearson's correlation has often been used to study the relationship between DRF and LDF (e.g., Schredl & Erlacher, 2004; 2011; Hess, Schredl & Goritz, 2016). This is a statistically inappropriate choice of test as when two ordinal variables are compared, the use of Pearson's correlation is incorrect (Laerd Statistics, 2016). Somers' d (Somers, 1962) or Jonckherre-Terpstra Test (Terpstra, 1952; Jonckheere, 1954) should be used when one wants to distinguish between a dependent (LDF) and an independent ordinal variable (e.g., DRF) for a cause-and-effect study. Otherwise, the Mantel-Haenszel test of trend (Mantel, 1963) should be used for purely observational studies of ordinal variables. In addition, when looking into ordinal-continuous relationships, Spearman's rank-order correlation or Polyserial correlation (Wherry, 1984) should preferably be used instead of Pearson's correlation (Laerd Statistics, 2016). In fact, Pearson's correlation has been consistently incorrectly used in LDF-continuous variable associations and/or the incorrect symbol is used (r instead of *rho* or r_s) even when in-text it is stated that Spearman Rank correlation is used (e.g., Schredl, Rieger & Goritz, 2018; Stumbrys & Erlacher, 2017).

One limitation of this study is that participants who've completed the study were online users on LD-related forums who are actively seeking to learn and talk about LDs. Testament to this

is that the current study had higher LDF than what was found in the LDF meta-analysis by Saunders, Roe, Smith & Clegg (2016). Moreover, online users of LD-related communities who seek to learn more about LDs and how to induce them may score higher in the OCEAN factor 'Openness to experience'. Previous research by Hess, Schredl & Goritz (2016) has demonstrated that 'Openness to Experience' impacts LDF scores positively (Hess, Schredl, Goritz, 2016). Thus, it may not be possible to generalise these findings to the wider population. In addition, although the present study did not find a greater association between prospective memory ability and LDF when compared to retrospective memory ability, the effect that prospective memory ability has on LDF cannot be fully discounted because how the MILD technique (which is thought to rely heavily on prospective memory) correlates with prospective memory ability was not investigated in this chapter. However, the following chapter investigates possible pro/retrospective memory associates of a LD induction success using a combination of three cognitive LD techniques (Reality Testing + WBTB + MILD) that includes MILD. Furthermore, the PRMQ might not be as sensitive in identifying differences on prospective memory ability as it is more focused on assessing through self-report measures as compared to assessing retrospective/prospective memory through a task.

3.4.2 Future directions

Despite these limitations, the present study has enhanced our understanding of the relationship between cognition, metacognition and LDF. It would be interesting to explore how, for example improving cognitive abilities such as memory and attention, coupled with LD induction techniques, can improve LDF. For example, Blagrove, Bell & Wilkinson (2010), demonstrated that performance in the Stroop test is correlated with LDF, but improving performance in the Stroop test has not been tested whether it improves LDF. Perhaps increasing attentional skills related to error detection through practising the Stroop test, especially when

coupled with an LD induction technique, could lead to higher LDF than by practising LD induction techniques alone. Hopefully, these findings will stimulate further investigation of this area.

In addition, the impact of performing dream recall related habits such as keeping a dream journal should be investigated in conjunction with LD induction techniques

3.4.3 Conclusion

This study sought to investigate individual differences in LDF and LD technique practises in online LD related communities. In general, the findings suggest a continuity of cognitive and metacognitive ability between waking and dreams. Additionally, waking habits associated with increasing DRF, such as sharing or keeping a dream diary also have an impact on increasing LDF and should be looked into further in future studies. The study also found that the traditional LD induction techniques that have been investigated in the scientific literature, such as reality testing, WBTB, WILD and MILD, are considered to be the most efficacious at inducing LDs. Finally, some of the best correlates associated with LD from the questionnaires used in this study have been identified and will be used as additional measures in the subsequent two study chapters, which focus on inducing LDs through different interventions.

CHAPTER 4

Investigation into the effectiveness of the Reality Check, Wake-Back-to Bed and Mnemonic Induction of Lucid Dream protocol

4.1 Introduction

Cognitive LD induction techniques are methods employed during wakefulness, or while falling asleep, whose aim is to "incubate" a lucid dream to happen, once the person is asleep (Stumbrys et al., 2012). Cognitive techniques are further divided into two main categories that are meant to help initiate lucid dreams from REM sleep and their results are termed either ''Dream-Initiated Lucid Dreams'' (DILDs) or Wake-Initiated Lucid Dreams (WILDs). DILDs are triggered solely by performing LD techniques during the day and/or before going to sleep which in turn 'incubate' an LD to happen, whilst WILDs are induced lucid dreams where there is no lapse of consciousness between wake and dream sleep as one is instructed to remain conscious while their body goes to sleep (i.e., muscle atonia sets in; Stumbrys et al., 2012).

The aim of the present study was to investigate the combination of three cognitive techniques: Reality Testing (RT), Wake Back To Bed (WBTB) and Mnemonic Induction of Lucid Dreams (MILD) which are techniques that are often used to induce DILDs, either in combination or by themselves (Stumbrys et al., 2012). The RT technique involves repeated questioning of oneself, throughout the day, of whether what is experienced is real or a dream, whilst performing specific actions that would lead to differential outcomes when performed in dreams. A common example of an RT action is the pinching of the nose while trying to breathe through it, a task that is of course impossible during wakefulness, but possible in dreams as the air passage is not actually blocked (Stumbrys et al., 2012). Repeated use of the RT techniques increases the

chance of dreaming about performing the RT with its accompanying question, thus, leading to the realisation that one is dreaming (Stumbrys et al., 2012).

In the WBTB method, one must wake one to two hours prior to one's natural waking time, stay awake for a short period and then go back to sleep. The brief awakening is thought to increase cortical activation during sleep, thereby increasing the likelihood of lucid dreams (Stumbrys et al., 2012; Smith & Blagrove, 2015). This is because areas implicated in lucid dreaming, such as frontotemporal areas, are more activated both when awake and during REM sleep when compared to normal dreaming (Voss et al., 2009; Dresler et al., 2012). In fact, an association with the frequency of alarm snooze button use in the morning and lucid dream frequency has been described in the literature (Smith & Blagrove, 2015).

In the MILD technique, while falling asleep, one must rehearse a dream and visualize becoming lucid in it simultaneously, developing the intention to remember that one is dreaming, by repeating the phrase: "The next time I'm dreaming, I will remember that I'm dreaming" (Stumbrys et al., 2012). The MILD technique was developed by LaBerge (1980) and while it is considered the most frequently tested cognitive LD induction technique (Stumbrys et al., 2012), up until Aspy et al (2017), it had only been only investigated by LaBerge and his colleagues (Edelstein & LaBerge, 1992; LaBerge, 1988; LaBerge, Phillips, & Levitan, 1994; Levitan, 1989, 1990a, 1990b, 1991a; Levitan & LaBerge, 1994; Levitan, LaBerge, & Dole, 1992).

The present study followed, to a certain extent, Aspy et al's (2017) protocol and questionnaires, who investigated three combinations of the RT, WBTB and MILD techniques. Aspy et al. (2017) recruited 169 participants and split them into three groups; RT + WBTB + MILD, RC

+ WBTB and RT only. This between-subjects study took place over two weeks, with Week 1 acting as a baseline and Week 2 where participants practised lucid dream induction techniques (according to the group to which they were assigned). The study found that among the group of 47 participants who combined all three techniques, participants achieved a 17% success rate in having lucid dreams over the period of attempting this combination over a week, whilst overall, 53.2% experienced at least one LD during the week of RC + WBTB + MILD practice. These LD success metrics were significantly higher compared to the baseline week where they did not practise any techniques. Within the RT + WBTB + MILD group, for those who were able to go to sleep within the first five minutes of completing the MILD technique, the success rate of lucid dreaming was much higher, at almost 46% of attempts, throughout the seven days of attempting the RC + WBTB + MILD combination. Moreover, those who reported LD induction success using the RC + WBTB + MILD technique, woke up significantly less tired in the morning and reported higher sleep quality the next day, indicating that lucid dreaming did not have any negative effect on sleep quality (Aspy et al., 2017).

Aspy et al (2017) used pen-and-paper format to collect responses from participants, a method that has been criticised and considered to introduce memory confounds in longitudinal studies where the participants retain the pen-and-paper questionnaires until the study is completed (Ribeiro, Gounden & Quaglino, 2018; Gounden & Guaglino, 2018). Specifically, when longitudinal studies are in pen-and-paper format and participants retain questionnaires until they've fully completed, memory effect confounds can be introduced by allowing participants to review past information. For example, reviewing previous reports can improve memory through repetition (Greene, 1992 cited by Karpicke & Roediger, 2007) and it can augment the risk of memory distortions, errors and reconstructions of action of reviewing previous reports (Schacter, Guerin, & St. Jacques, 2011).

The present study tried to minimise the possible effect of memory confounds by importing the entire study to an online format where participants cannot review previous entries. In addition, the present study sought to look more in-depth into the inter-individual differences between participants who are successful with the RC + WBTB + MILD technique. Firstly, a more thorough pre-test questionnaire was provided, to dig deeper into factors that may affect who will be more or less likely to achieve lucid dreams during the second week (where participants practise the RC + WBTB + MILD technique). Aspy et al. (2017) provided the following pre-test questionnaires: Demographic questions, general dream recall questions, a question examining lucid dream frequency per month and two questions asking about prior experience ("Have you ever tried to have lucid dreams by learning and then practicing a lucid dreaming technique?") and frequency of lucid dream induction techniques practice ("How often have you practiced a lucid dreaming technique recently (in the past several months)"). In our pre-test questionnaire, in addition to the questions mentioned above, to investigate inter-individual differences in successful deliberate LD induction, we included the short form of the Five-Facets of Mindfulness questionnaire (FFMQ-sf; Bohlmeijer et al., 2011), the Prospective and Retrospective Memory Questionnaire (PRMQ; Smith et al., 2000) and the Lucid dreaming Skills Scale (LUSK; Schredl, Rieger & Göritz, 2018) - questionnaires that were used and described in more detail in Chapter 3. In addition to asking participant's lucid dream frequency over the last few months, we included a question asking how many lucid dreams they have experienced in total in their lifetime and how old they were when they occurred for the first time. We will also inquire more about past RC + WBTB + MILD practice by asking questions such as whether participants had practised it before, how many times they've practised it and how successful it has been. We also enquired about consumption of substances/medications that have been found to affect sleep in the literature, in order to control for substances that can negatively impact the likelihood of LD. The PRMQ which measures the frequency of the

frequency of prospective and retrospective memory slips in everyday life (Smith et al., 2000), was used in order to mostly investigate the effect of retro/prospective memory ability has on the RT and MILD techniques. We are particularly interested in investigating the effect of prospective memory on improving LD induction rate with the aforementioned techniques. The act of remembering to conduct RTs throughout the day and the MILD technique is thought to make use of prospective memory (LaBerge & Ornstein, 1985; Stumbrys et al., 2012; Aspy et al., 2017). Practisers of the MILD technique, while falling asleep, must form an intention in the future to remember to realise that they are dreaming once they are dreaming, repeating sentences such as "Next time I am dreaming I want to remember that I am dreaming". In the pre-test questionnaire, we also included the Five Facets of Mindfulness Questionnaire (FFMQ; Bohlmeijer et al., 2011) to measure participants' mindfulness, as previous research has found links between mindfulness, meditation frequency and lucid dream frequency, as well as increased ability to control the lucid dream (Gackenbach, Cranson, & Alexander, 1986; Hunt 1991; Stumbrys & Erlacher, 2017). Up until now, past studies have not looked into how differences in mindfulness affect LD induction rates in longitudinal studies where participants have been asked to actively try cognitive LD induction techniques.

In addition, the 'constant sum' retrospective measure of dream memory that provided in Chapter 3 was included which asked participants to estimate a percentage of how complete their dream memory was in the days where they have woken up remembering that they dreamt the night before (during the past several months). As mentioned in chapter 3, this question was adapted and modified from Aspy et al. (2017) who used the categories as categorical measures for each remembered dream during the two-week protocol. As a final pre-test question, we gave participants the Lucid Dream Skills questionnaire (LUSK; Schredl, Rieger, Goritz, 2018) which measures inter-individual differences in lucid dreaming skills across two factors

(awareness and control); this is in order to investigate differences in lucid dream skills in participants who successfully experience LDs during the two-week protocol and to look whether high-skilled lucid dreamers experience longer durations of lucid dreaming.

During Week 1, participants filled in a logbook containing questions identical to Aspy et al (2017), aimed at finding out how many dreams they recalled from last night (DC; Dream Count), their dream recall frequency (L DRF; the percentage of days on which there was dream recall), a categorical operationalization of how complete their dream memory was (L DQ; dream quantity) containing four categories (Fragmentary, Partial, Majority and Whole), their lucid dream recall and duration (if they had any) and various sleep-related questions (such as sleep duration, sleep quality). The improvement from Aspy's Week 1 logbook was the inclusion of the Lucidity and Consciousness in Dreams scale (LuCiD; Voss et al., 2013), which measures dream consciousness over eight factors (insight, control, dissociation, memory, realism, positive & negative emotion). The LuCiD scale allows us to ascertain possible shifts in dream consciousness factors in a continuum from Week 1 to Week 2, regardless of lucid dream occurrence. The inclusion of a baseline week not only serves as a comparator to Week 2, but in and of itself was used to investigate how several of our pre-test measures (e.g., DRF, LDF, FFMQ, PRMQ, etc) impact Week 1 dream consciousness and whether they can be used to predict subsequent LD induction success during Week 2.

During Week 2, participants performed RCs during the day, and the WBTB + MILD techniques at night. They were instructed to set up their alarm 4-5 hours after they had slept or to wake up 1-2 hours before their normal waking time. When participants woke up to perform the MILD technique, they were asked to complete a questionnaire containing all the questions from Aspy et al's (2017) Week 2 log-books and to fill out a form regarding their 'dream signs'. Thus, one

of the key differences from Aspy et al's (2017) second week protocol, was the addition of a questionnaire in which participants input the "dream signs" that they experienced in the dream they had before waking up, or from the last dream they remember if they don't remember having dreamt on that night (Appendix 4.1). A definition of a dream sign is "a peculiar event or object in a dream that can be used as an indicator that you are dreaming" (Levitan, 1992, p1). Levitan (1992) categorised these dream signs into four distinct categories: 1) dream signs that involve the ego/self; 2) dream signs about dream characters; 3) objects and 4) dream setting. These four categories come with various subcategories (such as Form, Role, Action, Time, Place – see Appendix 4.1 for thorough description of categories and subcategories). The aim of including a dream sign questionnaire was to increase participant's critical thinking about the dream(s) they had just experienced (thereby increasing information processing) and to use their dream signs for the rehearsal part of the MILD technique.

A final key difference from Aspy et al's (2017) protocol, was the addition of an audio guided progressive relaxation technique and audio guided MILD (Appendix 4.2). Once participants completed the pre-MILD questionnaire, they were asked to listen to the audio guided progressive relaxation + MILD script. As mentioned previously, in Aspy et al (2017), participants who fell asleep within five minutes of practising the MILD technique had a 46% chance of having a lucid dream (Aspy et al., 2017). Thus, the inclusion of the audio guided progressive relaxation technique script was to aid participants in falling asleep sooner while practising the MILD technique. Following the progressive relaxation technique, the audio guided MILD script had the aim of ensuring correct practise of the MILD technique. After waking up again after practising the MILD technique, participants were asked to complete questions about their experience with questions taken from the Aspy et al (2017) Week 2 log

book and the LuCiD scale to compare differences in dream consciousness from Week 1 to Week 2 in both those who succeeded in lucid dreaming and those who did not.

Our hypotheses were as follows:

1. Participants who have reported having higher LDF in the pre-test questionnaire will report higher LuCiD scores in both weeks
2. Participants who have reported prior higher success rates with the RT + WBTB + MILD technique in pre-test questionnaire will report higher LuCiD scores in Week 2
3. Participants will, on average report higher LuCiD scores in Week 2 than in Week 1 (regardless if they became lucid or not)
4. Participants with higher FFMQ scores will report higher LuCiD scores in both Week 1 and Week 2 than participants with low FFMQ scores
5. Participants who score lower on the PRMQ questionnaire will report higher LuCiD scores, particularly in the LuCiD factor 'MEMORY' in both weeks. In addition, during Week 2, they will perform more reality checks and will report higher LD induction rates.
6. In week 2, participants who report sleeping soon after practising the MILD technique will report, on average, more lucid dreams.

4.2 Methods

4.2.1 Participants

Overall, 594 participants (469 men, 107 women, 3 Transgender Males, 4 Transgender Females, 6 Non-conformists/Gender Variants and five who did not disclose gender) completed the pre-test questionnaire. The mean age of the pre-test sample was 23.54 ± 7.12 (range: 13 to 65 years). Participants were recruited from subreddit, r/LucidDreaming, Dreamviews.com and ld4all.com websites.

4.2.2 Materials

Screening questionnaire

Participants were asked to provide their email address in order to be sent questionnaires and to be identified throughout the two-week study.

4.2.2.1 Demographics questionnaires

Demographics questions included age, gender and occupation. Participants were provided with a list of sleep affecting substances/medications and asked whether they would be taking any of them during the two-week protocol (“Yes”, “No”, “Prefer not to say”). The list included medications such as anti-arrhythmics, beta blockers, clonidine, corticosteroids, diuretics, medications containing alcohol or caffeine, nicotine replacement products, antihistamines, antidepressants, sympathomimetic stimulants, theophylline, thyroid hormone and illegal substances such as THC, Cocaine, Heroin, MDMA, LSD and psychoactive mushrooms.

4.2.2.2 Prospective and Retrospective Mistake Questionnaire (PRMQ)

The PRMQ (Smith, Della Sala, Logie & Maylor, 2000) which assesses the frequency of retrospective and prospective memory mistakes and was described in Chapter 3 was used.

4.2.2.3 Five-Facets of Mindfulness short form (FFMQ-sf)

The short form version of the PRMQ, whose full version was described in Chapter 4, was used (Baer, Smith, Hopkins, Krietemeyer & Toney, 2006; Bohlmeije, Ten Klooster, Fledderus, Veehof & Baer, 2011). The PRMQ-sf reduces the full PRMQ's questions from 39 to 24 (Bohlmeije, Ten Klooster, Fledderus, Veehof & Baer, 2011).

Dream questionnaires

Dream behaviour was measured using 4 questionnaires: Dream Recall Frequency (DRF), Lucid Dream Frequency (LDF), Lucid Dream Skills questionnaire (LUSK; Schredl, Rieger, Goritz, 2018) dream recall completeness (DRC) questionnaire. The dream recall completeness (DRC) questionnaire refers to the modified question from Aspy et al. (2017) described in previous chapter which asks to estimate a percentage in four categories (fragmentary, partial, majority, whole) of how complete their dream memory in the past several months.

4.2.2.4 LD technique practice questionnaires

To ascertain various aspects the practice of previous lucid dream techniques, participants were asked if they had ever tried to have lucid dreams by learning and practising a lucid dream

technique and how often they had practised such a technique in the past several months (0 = Never, 1 = Less than once a month, 2 = About once a month, 3 = Two or three times a month, 4 = About once a week, 5 = Several times a week, 6 = Almost every morning).

The "deliberate vs spontaneous lucid dreaming" 5-point scale described in Chapter 5 was also used to elucidate how many of their lucid dreams happened spontaneously versus induced through a technique.

A question asking whether participant had practised the combination of WBTB, MILD, and Reality check was provided. For participants who had practised this combination of techniques before, they were also asked how many times they had practised this combination before and how successful (in percentage) was at inducing lucid dreams.

Week 1 questionnaire

In Week 1, questionnaires contain an email entry for participant identification and a question asking participants to input number of test day (1 to 7) to track their progress. The same questions used in Aspy et al (2017) were used for Week 1 of the present study, with the addition of the Lucidity and Consciousness in Dreams Scale (LuCiD; Voss et al., 2013) which was given to participants to complete at the end of the questionnaire.

Specifically, as per Aspy et al's (2017) protocol, participants were asked whether they recalled having dreamt at all last night. If participants answered "Yes", they were then prompted to provide a brief title for each dream they could remember as well as provide dream memory strength/completeness categorical rating (fragmentary, partial, majority and whole) for each

dream dream as implemented in Aspy et al. (2017). Participants were then asked how much they were able to recall of their dreams from last night with the following options available and coded as 1 = Nothing specific, 2 = Hardly anything, 3 = A small amount, 4 = A moderate amount and 5 = A large amount (Aspy et al., 2017). Participants were then asked how difficult it was for them to remember their dreams from last night with the following choices which were coded as, 1 = Not at all difficult, 2 = Slightly difficult, 3 = Somewhat difficult, 4 = Quite difficult and 5 = Very difficult (Aspy et al., 2017). Subsequently, participants whether participants experienced any lucid dreams last night and to estimate how (approximately) they thought they were lucid dreaming for, expressed in minutes (Aspy et al., 2017).

Participants were then asked to estimate how long they spent sleeping last night, and how good was their overall sleep quality last night with the following options 1 = Terrible, 2 = Poor, 3 = Okay, 4 = Good and 5 = Excellent (Aspy et al., 2017), how tired they felt in the morning upon waking up (1 = Not at all tired, 2 = Slightly tired, 3 = Somewhat tired, 4 = Quite tired and 5 = Very tired) and how sleep deprived they were the day before (1 = Not at all, 2 = Slightly, 3 = Somewhat, 4 = Quite and 5 = Very).

The LuCiD scale (Voss et al., 2013) was then provided is a 27-item scale which splits dream consciousness into eight factors (INSIGHT; How aware they were that what they were experiencing was a dream, CONTROL; how able they were to control various aspects of the dream, THOUGHT; how logical was their thinking processes, REALISM; the perceptual realism of their dream when compared to waking life, MEMORY; the ability to access memory elements of waking life, DISSOCIATION; experiencing the dream from a third person perspective, and NEGATIVE and POSITIVE EMOTION; the types of emotions experienced in the dream).

Week 2 "Waking up to perform MILD" questionnaire

In the same manner as Aspy et al (2017), the questionnaire provided text entries for participants to give brief titles of dreams experienced prior to awakening to perform MILD and to provide how complete their dream memory was for each dream remembered. Participants were asked how much they recalled of their dreams upon waking to perform MILD (0 = Nothing specific, 1 = Hardly anything, 2 = A small amount, 3 = A moderate amount, 4 = A large amount. They were then asked how difficult it was for them to remember their dreams upon waking (0 = Not at all difficult, 1 = Slightly difficult, 2 = Somewhat difficult, 3 = Quite difficult, 4 = Very difficult). Subsequently, they were asked how clear their dream memory was upon waking (0 = Not at all clear, 1 = Slightly clear, 2 = Somewhat clear, 3 = Quite clear, 4 = Very clear) and how certain they were that they were in the middle of a dream when the alarm woke them up (+2 = Definitely yes, +1 = Probably yes, 0 = Might or might not, -1 = Probably not, -2 = Definitely not. In addition, they were asked if they had any lucid dreams prior to waking up and how long they were lucid (in minutes) and how tired they felt upon waking up to perform mild (0 = Not at all tired, 1 = Slightly tired, 2 = Somewhat tired, 3 = Quite tired, 4 = Very tired).

Finally, using the dream sign categories (Levitan, 1992), they were asked to indicate and briefly describe the dream signs they experienced prior to waking up to perform MILD (Appendix 4.1).

Audio-guided progressive muscle relaxation and MILD technique

The audio guided progressive muscle relaxation and MILD techniques (Appendix 4.2) were included in a single audio file (10:31 minutes in total) with the relaxation technique lasting 7:20 minutes and the guided MILD technique portion of the tape lasting 3:11 minutes.

Progressive relaxation techniques involve learning to monitor the tension in specific muscle groups by first tensing each muscle group and subsequently, releasing tension, thereby directing attention to the differences felt during tension and relaxation.

Week 2 "Post-technique" questionnaire

After having woken and practised WBTB + MILD they were asked to complete the "post-technique" questionnaire. The questionnaire asked if participants could recall having dreamt at all after performing MILD. A questionnaire provided text entries for participants to give brief titles of dreams experienced (if they had chosen "Yes" to having any recollection of having dreamt) and to rate their dream memory for each dream remembered. Questions the from the "Waking up to perform MILD" questionnaire pertaining to dream memory, dream recall, dream memory retrieval difficulty, clarity of dream memory and lucid occurrence, lucid dream duration where used. Participants were asked about their overall quality of sleep (1 = Terrible, 2 = Poor, 3 = Okay, 4 = Good, 5 = Excellent), how tired they felt in the morning (0 = Not at all tired, 1 = Slightly tired, 2 = Somewhat tired, 3 = Quite tired, 4 = Very tired). They were asked to state how many reality tests they performed yesterday and how many times they repeated the sentence "Next time I am dreaming, I will remember that I am dreaming" when they practised the MILD technique.

In addition, participants were asked to indicate how motivated they were about performing the MILD technique after the alarm went off (0 = Not at all motivated, 1 = Slightly motivated, 2 = Somewhat motivated, 3 = Quite motivated, 4 = Very motivated), how difficult it was to focus on the MILD technique (0 = Not at all difficult, 1 = Slightly difficult, 2 = Somewhat difficult, 3 = Quite difficult, 4 = Very difficult). Participants were asked to how long (approximately) it took for them to fall asleep after listening to the audio guided MILD tape and if they had fallen

asleep whilst performing MILD ("Yes, I fell asleep whilst performing MILD", "No, I stopped performing MILD at one point", "Unsure"). Participants who reported that they had stopped performing MILD at one point were asked to indicate (in minutes) how long it took for them to get to sleep after they stopped performing MILD. Participants were then asked to indicate how many minutes they spent performing the MILD technique after the audio tape had finished. The questionnaire then included a question asking how many days it had been since they last attempted the RC + WBTB + MILD combination. The LuCiD scale (Voss et al., 2013) was provided at the end of the questionnaire, which enquired about participants' dream consciousness for the dream(s) they had after practising WBTB + MILD.

4.2.3 Procedure

Upon completing the pre-screening questionnaire, participants received an email containing information about Week 1 and a Qualtrics link to Week 1 questionnaires. Information about Week 1 included a brief discussion of the difference between normal and lucid dreams and suggestion to complete questionnaire as soon as they wake up, as dream memories fade quickly upon waking. In the information email participants were told to not attempt any lucid dream induction techniques.

After completing each day of Week 1 questionnaires, participants received an email reminder to complete next day's questionnaire. Upon completing the last Week 1 questionnaire (day 7) participants received an email containing information about Week 2 links to the pre-technique questionnaire, the post-technique questionnaire and link to the guided audio file. Week 2 information booklet included a description of RC + WBTB + MILD techniques and about Dream Signs. During Week 2 participants were instructed to complete pre-technique questionnaire after waking up in the middle of the night and before listening to the audio guided

tape and the post-technique questionnaire after having awoken again. After completing each day participants were sent an email reminder to complete the next day. The email reminder also informed them that it was okay to not try the techniques consecutively, especially if they were feeling sleep deprived. To increase motivation, when participants said they had not had a lucid dream, they received an email informing them to not worry and to keep trying. When participants said they did have a lucid dream they were congratulated and told to keep trying to see how many more lucid dreams they could induce in the remainder of Week 2.

4.3 Results

4.3.1 Choice of statistical tests

Aspy et al. (2017) chose to conduct blanket non-parametric tests on all variables, citing a large number of non-normally distributed variable data ("Most variables were not normally distributed and nonparametric tests were used in all cases"; Aspy et al., 2017, p.216). Here the appropriate parametric or non-parametric equivalent test will be performed for each variable analysed according to Shapiro-Wilks test of normality significance value.

Week 1 and screening measures results

4.3.2 DRF and other dream recall related measures

On average participants reported a mean DRF of 5.41 ±.48 with a mode response value of 6; thus, most participants reported being able to recall having dreamt several times during the week. On average, participants reported 3.36 ± 2.36 of days where they recalled having dreamt. A Spearman's rank-order correlation was run to assess the relationship between general DRF

and total number of dream recall days, in 311 participants. There was a statistically significant, small positive correlation between DRF and total dream recall days in Week 1, $rs(311) = .273$, $p < .001$. These results show that general dream memory recall ability is correlated with the number of dream recall days. However, direct comparisons to investigate whether there is an over/underestimation between general DRF and log-book measures of DRF can't be made because general DRF was assessed through a 7-point Likert scale and not through a retrospective number estimation of dream recall days. As such, direct comparisons can't be made unlike in Aspy, Delfabbro & Proeve (2016) who found that retrospective dream recall measures appear to underestimate true dream recall rates acquired through log-book measures. Nevertheless, this result suggests that general DRF that is estimated retrospectively over a longer timescale is associated with log-book measures of DRF over a short timescale of one week.

Furthermore, there was a statistically significant, small positive correlation between DRF and average dream recall amount (DRA), $rs(311) = .274$, $p < .001$. In addition, there was a statistically significant, moderately negative correlation between general DRF and average dream recall difficulty (DRD), $rs (311) = -.348$, $p < .001$. Thus, participants who reported higher general dream recall ability (DRF) not only were able to recall having dreamt more and were able to recall more detail, they also experienced less difficulty in recalling their dreams.

Next, the relationship between the past few months memory dream recall quantity (general DRQ) and Week 1's DRA was explored. There was a statistically significant, small negative correlation between and DRA and percentage of fragmentary dream recall, $rs(273) = -.248$, $p < .001$; a small positive correlation with percentage of majority dream recall, $rs(273) = .206$, $p = .001$ and a small positive correlation with percentage of whole dream memory recall, $rs(273) = .215$, $p < .001$. Thus, these results show that participants who report a smaller percentage of

fragmentary dream recall and higher percentage of majority and whole dream memory recall in the past few months were able to recall more dream details during Week 1, suggesting that this ability is somewhat stable.

Week 1's DRA was not correlated with prospective and retrospective memory measures of the PRMQ, $p > .05$. This result suggests that retrospective and prospective memory ability is not correlated with the ability to recall more/less amount of dream memory details.

4.3.3 Week 1 LuCiD scores and general DRF correlations

The relationship between LuCiD scale factors (INSIGHT, CONTROL, DISSOCIATION, MEMORY, REALISM, POSITIVE and NEGATIVE EMOTION) and DRF, Week 1 DRA, LDF, PRMQ and FFMQ were evaluated next.

Firstly, there was a significant small positive correlation between total LuCiD scale score and general DRF, $r_s(304) = .184$, $p = .001$. Looking into the relationship between the individual LuCiD factors and general DRF, the LuCiD factors INSIGHT, CONTROL, MEMORY and THOUGHT were all significantly correlated with general DRF, $p < .05$, while factors DISSOCIATION, REALISM and POSITIVE/NEGATIVE EMOTION were not significantly correlated, $p > .05$. Specifically, there were small positive correlations between general DRF and INSIGHT, $r_s(304) = .121$, $p = .036$; CONTROL , $r_s(304) = .205$, $p < .001$; MEMORY, $r_s(304) = .119$, $p = .039$; and THOUGHT, $r_s(304) = .173$, $p = .002$. These results show that higher DRF is correlated with higher cognitive dream abilities.

4.3.4 Week 1 LuCiD scores and DRA

Week 1 average DRA was positively correlated with all LuCiD factors except the factor DISSOCIATION. Specifically, there were statistically significant small positive correlation between DRA and LuCiD factors, INSIGHT, rs (308) = .190, p = 001; CONTROL, rs (308) = .204, p < .001; MEMORY, rs (308) = .259, p < .001; REALISM, rs (308) = .246, p < .001 NEGATIVE EMOTION, rs (308) = .182, p = .001 and moderate positive correlations with THOUGHT, rs (308) = .414, p < .001 and POSITIVE EMOTION, rs (308) = .305, p < .001. Even when looking at the subset of participants who did not experience any LDs in Week 1, the same statistically significant correlations were observed, with minimal spearman strength of correlation reductions. These results show that in addition to higher general DRF levels being associated with higher dream consciousness, the ability to recall a greater amount of dream details is also correlated higher dream consciousness.

4.3.5 Week 1 LuCiD scores LDF correlations

Table 4.1 Significant correlations between LDF and Week 1 LuCiD scale total score and LuCiD factors. $LDF_{adjusted}$ correlations have participants who experienced LDs in Week 1 removed from the sample size.

Significant LDF correlations	**N**	**Spearman rank (rs)**	**Interpretation**
LuCiD(total)	304	.202**	small
INSIGHT	304	.191**	small
CONTROL	304	.236**	small
DISSOCIATION	304	.191**	small
Significant $LDF_{adjusted}$ correlations	**N**	**Spearman rank (rs)**	**Interpretation**
vs CONTROL	267	.162*	small

$LDF_{adjusted}$ vs MEMORY	267	.140*	small

*p < .05. **p < .01

There was a significant small positive correlation between total LuCiD scale score and LDF, rs(304) = .202, p < .001. Similarly to the general DRF and LuCiD scale factor relationship findings, there were small positive correlations found between LDF and LuCiD scale factors INSIGHT, rs(304) = .191, p = .001, CONTROL, rs(304) = .236, p < .001, MEMORY, rs(304) = .191, p = .001 and THOUGHT, rs(304) = .140, p = .015. These results suggest that higher LDF is associated with higher dream consciousness abilities in general. Subsequently, LDF associations with LuCiD scale factors were investigated in those who did not report any LDs during Week 1. Small positive correlations found between LDF and LuCiD scale factors CONTROL, rs(267) = .162, p = .008 and MEMORY, rs(267) = .140, p = .022. This finding suggests that persons who report experiencing LDs more often also experience higher dream consciousness abilities even in non-LD dreams.

4.3.6 Week 1 LuCiD scores and PRMQ correlations

The relationship between total score of the frequency of prospective and retrospective memory mistakes (assessed by the PRMQ) and the LuCiD factors was investigated. There were significant small positive correlations between total retrospective and prospective memory frequency errors and the LuCiD factor NEGATIVE EMOTION, rs(304) = .140, p = .015, and rs(304) = .218, p < .001, respectively. The non-significant results in the LuCiD factors, INSIGHT, CONTROL, MEMORY, REALISM and THOUGHT suggest that there is no connection between the level of cognitive abilities that are expressed in dreams and retro/prospective memory ability. The significant negative dream emotion association with higher propensity to make retro/prospective memory mistakes suggests that stress and negative emotion during wake derived from making frequent retro/prospective memory mistakes affects

dream affect negatively. Another hypothesis is that decreased memory ability during wake might lead to an even further decreased cognitive ability whilst dreaming which may lead to more confusing and stressful dreams.

4.3.7 Week 1 LuCiD scores and FFMQ correlations

Table 4.2 Summary table showcasing significant correlations between Week 1 LuCiD factors and FFMQ scores.

Significant LuCiD MEMORY correlations	**N**	**Spearman rank (rs)**	**Interpretation**
FFMQ DESCRIBE	304	.125*	Small
FFMQ NON-JUDGE	304	-.117*	
Significant LuCiD THOUGHT correlations	**N**	**Spearman rank (rs)**	**Interpretation**
FFMQ OBSERVE	304	.211**	Small
FFMQ DESCRIBE	304	.148*	Small
Significant LuCiD POSITIVE EMOTION correlations	**N**	**Spearman rank (rs)**	**Interpretation**
FFMQ DESCRIBE	304	.128*	Small
Significant LuCiD NEGATIVE EMOTION correlations	**N**	**Spearman rank (rs)**	**Interpretation**
FFMQ NON-REACT	304	-.176*	Small

*p < .05. **p < .01

Finally, the relationship between the LuCiD scale and FFMQ scores was investigated. For the LuCiD factor MEMORY, there was a significant small positive correlation with FFMQ's factor DESCRIBE, rs (304) = .125, p = .030 and a significant small negative correlation with factor Nonjudge, rs (304) = -.117, p = .042. For LuCiD factor THOUGHT, there were significant

small positive correlations with FFMQ's factors OBSERVE, rs (304) = .211, p < .001 and DESCRIBE, rs (304) = .148, p = .010. For the LuCiD factor POSITIVE EMOTION, there was a small positive correlation with the FFMQ factor DESCRIBE, rs (304) = .128, p = .026. Lastly, there was a significant small positive correlation between the LuCiD factor NEGATIVE EMOTION and the FFMQ factor NON-REACT, rs (304) = -.176, p = .002. Thus, correlations between FFMQ factors and various LuCiD scale factors, particularly MEMORY and THOUGHT, may point out the mode through which higher mindfulness has been associated with higher LDF in past literature (e.g., Stumbrys, Erlacher & Malinowski, 2015; Stumbrys & Erlacher, 2017; Baird, Riedner, Boly, Davidson & Tononi, 2018). This is discussed in more detail in Discussion section of this chapter.

4.3.8 Week 2 results

In total, 85 participants went on to complete at least one day of Week 2. Specifically, 40 participants completed only up to Week 2's 1st day (47.1%), 15 participants completed two days (17.6%), 7 participants three days (8.2%) and 2 participants completed four and five days, 4 participants completed six days and 15 participants completed the whole of week 2. This result suggests high attrition rate throughout the days of Week 2. Due to this, several variables such as the total number of lucid dreams experienced will also be averaged by the number of days of Week 2 that were completed, to protect against possible skewed results.

4.3.9 Differences between Week 2 lucid dreamers vs Week 2 normal dreamers

4.3.9.1 DRF, LDF and LuCiD differences

Independent samples t-tests and Mann-Whitney U tests were run to determine if there were differences between participants who experienced at least one LD during Week 2 (hereafter referred to as 'Week 2 lucid dreamers') and those who didn't (hereafter referred to as 'Week 2 normal dreamers').

Week 2 lucid dreamers remember their dreams (general DRF) and experience lucid dreams more frequently (general LDF) than the Week 2 normal dreamers, $U = 464$, $Z = -2.172$, $p = .030$ and $U = 359$, $z = -3.238$, $p = .001$, respectively. Indeed, the most frequent DRF and LDF response that Week 2 lucid dreamers gave was that they remember having dreamt almost every morning and that they experience lucid dreams about 2-4 times a year, whereas the Week 2 normal dreamers most frequent DRF and LDF response was that they remembered having dreamt several times a week and that they experience lucid dreams about once a year. To account for possible physiological inability to lucid dream affecting LDF group differences results, participants who never experienced LDs in their lifetime were removed for the following test only and the two groups LDF was re-tested ($N = 65$). Differences in LDF between the two groups remained the same even after removing participants who have never experienced LDs in their lifetime, $U = 315.5$, $Z = -2.62$, $p = .009$. Therefore, the results suggest that the ability to remember dreams and the frequency which they've experienced lucid dreams in their life affected the outcome of whether one would be successful in Week 2.

Both groups' 'baseline' ability to lucid dream was further investigated by looking into differences between the two groups in Week 1's LuCiD's scores. LuCiD factor INSIGHT during Week 1 was statistically significantly higher in the Week 2 lucid dreamers (Mdn = 6.33) than in the Week 2 normal dreamers (Mdn = 3.5), $U = 457$, $z = -2.109$, $p = .035$. In addition, the LuCiD factor THOUGHT during Week 1 was statistically significantly higher in Week 2

lucid dreamers (M= 9.5, SD = 3.53) than in Week 2 normal dreamers (M = 7.5, SD = 7.5), t (73) = 2.360, a mean difference of 2.02, 95% CI [.31, 3.72], p = .021.

The general DRF, LDF and Week 1 LuCiD factor differences in INSIGHT and THOUGHT, denote that Week 2 lucid dreamers on average experienced lucid dreams more often in their lives and experience higher metacognitive and cognitive abilities whilst dreaming.

4.3.9.2 Number of days completed in Week 2

Differences in the number of Week 2 days completed between Week 2 lucid dreamers and Week 2 normal dreamers were found. Week 2 lucid dreamers went through more Week 2 days than Week 2 normal dreamers, U = 292.5, Z -3.736, p < .001. Most Week 2 lucid dreamers completed all seven days of trying to lucid dream with the study's technique combination while most Week 2 normal dreamers competed only 1 day of Week 2. This result suggests that participants who persisted in attempting the RC + WBTB + MILD technique were more likely to experience lucid dreams in week 2 or vice versa.

When examining those who did LD in week 2, five participants experienced LDs before attempting the WBTB + MILD technique, a result that can be attributed solely to the effect of practising the RC technique. Specifically, when participants woke up to do the WBTB + MILD technique, two participants experienced LDs in the first day, one participant on the fifth day and two participants on the seventh day. After practising the WBTB + MILD technique, twelve participants reported experiencing LDs in the first day, four in the second day, six in the third day, three in the fourth day, four in the fifth day, two in the sixth day and three in the seventh day. This suggest that the RC technique alone is much less effective than when it is combined with the WBTB + MILD techniques as there were much less LDs experienced prior to practising the WBTB + MILD techniques

4.3.9.3 PRMQ and FFMQ differences

There were no statistically significant differences in PRMQ and FFMQ scores between Week 2 lucid dreamers and Week 2 normal dreamers, $p > .05$, suggesting that mindfulness and retrospective/prospective memory ability was not a factor in LD induction.

4.3.9.4 Past experience with the RC + WBTB + MILD technique and lucid dream technique practise frequency

Out of the 75 participants who took part in at least one day of Week 2, 9 participants who had prior experience with the RC + WBTB + MILD technique combination experienced lucid dreams in Week 2 (33.3% of those who had an LD), while 18 participants with no prior RC + WBTB + MILD technique combination experience experienced lucid dreams (66.7% of those who had an LD). Due to small sample sizes, Fisher's exact test was run. The proportion difference of 0.33 between the two independent binomial proportions was not statistically significant, $p = .419$. Therefore, prior experience with the RC + WBTB + MILD combination technique does not seem to affect whether participants experienced LDs in Week 2. There was no significant difference between Week 2 lucid dreamers and Week 2 normal dreamers in the number of times they attempted the RC + WBTB + MILD technique nor in the estimated success rate of past tries with the RC + WBTB + MILD technique, $p > .05$. In addition, there was no significant difference in lucid dream technique practise frequency, $p = .226$. These results suggest that general LD practise frequency and prior experience and frequency of practising the RC + WBTB + MILD technique are not factors in the LD success in Week 2.

4.3.9.5 Sleep onset-latency (SOL) following the guided MILD tape

Participants estimated sleep onset-latency (SOL) after listening to the guided MILD audio and continuing to practise MILD while falling asleep was investigated to ascertain whether there were differences between the Week 2 lucid dreamers and Week 2 normal dreamers: no significant difference was found, $p = .098$. The results suggest that SOL while practising MILD was not a factor in LD induction. This result comes in contrast with Aspy et al. (2017) who found that the smaller the SOL the more likely participants were to lucid dream.

4.3.9.6 Week 1 vs Week 2 LD total scores

A paired-samples t-test was used to determine whether there was a statistically significant mean difference between the number of LDs experienced in Week 1 vs Week 2. Week 1 vs Week 2 scores were compared only for participants who went through week 2 ($N = 91$) A Wilcoxon Signed Ranks test showcased that participants experienced more LDs in Week 2 than in Week 1, $Z = -2.288$, $p = .022$. This result demonstrates that practising the technique led to an increase in LDs.

4.3.9.7 Week 1 vs Week 2 LD total, average and LD duration

During Week 1, 39 out of 575 participants, experienced LDs at least once, amounting to 6.78% of Week 1's sample size.

In Week 2, 5 out of 56 participants experienced LDs at least once before performing the WBTB+MILD method (8.93%). This result is more suggestive of LDs being induced solely through the RC method. After performing the WBTB+MILD technique out of 56 participants, 23 experienced lucid dreaming at least once (41.07%).

A paired-samples t-test was used to determine whether there was a statistically significant difference in the total number of LDs experienced in Week 1 and Week 2 in 91 participants. Participants' LD occurrence in Week 1 and Week 2 in was also averaged with the aim to protect against differences between the amount of days in Week 2 that participants practised the RT + WBTB + guided MILD combination. There was a near statistically significant difference in the total number of LDs experienced between Week 1 and Week 2 and a significant difference between the average number of LDs experienced between Week 1 and Week 2. Specifically, there was a near statistically significant increase in the total number of LDs experienced from Week 1 (M = .25, SD = .71) to Week 2 (M = .42, SD = .76), t (90) = -1.971, p = .052. When averaging the LD scores (1 = scored as LD and 0 = no LD for each day of each of the two week) for Week 1 and 2, a statistically significant increase in average LD induction rate from Week 1 (M = .04, SD = .09) to Week 2 (M = .09, SD = .71) was demonstrated, t (90) = -2.409, p = .018. There was no significant difference between Week 1 and Week 2 for LD duration, p > .05.

4.3.9.8 Week 1 vs Week 2 LuCiD dream scale

A paired-samples t-test was used to determine whether there was a statistically significant mean difference between dream consciousness experienced in Week 1 and Week 2, assessed by differences in the factors INSIGHT, CONTROL, DISSOCIATION, THOUGHT, MEMORY,

REALISM and POS/NEGATIVE EMOTION of the LuCiD scale. Significant differences between the two Weeks were found in the factors, INSIGHT, CONTROL and DISSOCIATION in the 56 participants who went on to complete at least 1 day of Week 2 and had also completed the LuCiD scale. For factor INSIGHT, participants experienced a statistically significant increase from Week 1 to Week 2, Z = -2.097, p = .036. For factor CONTROL, participants experienced an almost statistically significant increase in experienced dream control from Week 1, Z = -1.902, p = .057. For factor DISSOCIATION, participants experienced an increase in feelings of dream dissociation from Week 1 to Week 2, Z = -4.093, p < .001. These results suggest that the factors INSIGHT, CONTROL and DISSOCIATION are most associated with lucid dreaming.

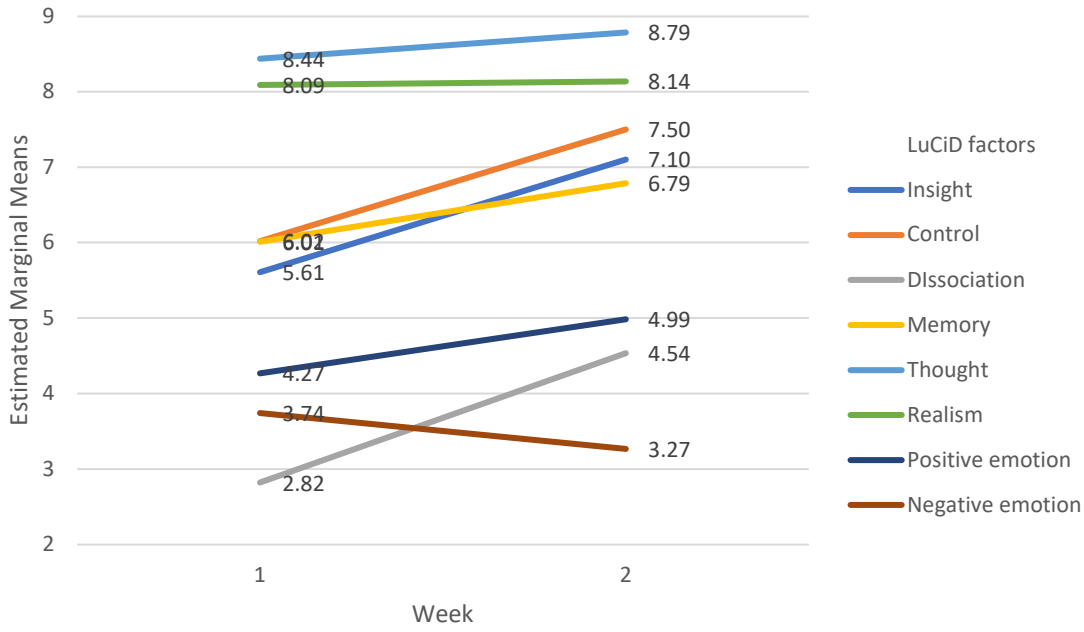

Figure 4.1. The figure displays the average LuCiD scale Voss et al (2013) factor changes from Week 1 to Week 2.

4.3.10 WEEK 2 reality checks (RCs) relationship with average LD induction rate and LuCiD scale

During week 2, participants on average performed 8.72 ± 4.46 RCs per day. The lowest average of RCs performed was 2 and maximum was 24.29. The relationship between the average number of RCs performed per day in Week 2 and the average LD induction rate in Week 2 was investigated. There were no significant correlations found between RC use and average LD induction rate, $p > .05$. Next, the relationship between average number of RCs performed per day in Week 2 and average LuCiD scores was explored. Again, no significant findings were observed, $p > .05$. Thus, the number of RCs performed did not seem to impact LD induction rates.

4.3.11 Technique motivation and focus relationship with average LD induction rate and LuCiD scale

The relationship between technique focus and motivation with average LD induction rate and the LuCiD scale in Week 2 was considered. There were no significant correlations found between motivation to perform the LD technique and LDs nor with the LuCiD scale, $p > .05$. Next, the relationship between how focused participants were to perform the LD technique in Week 2 and LuCiD scores was explored. No significant findings were observed, $p > .05$. Thus, these results suggest that motivation and focus on the technique are not factors for inducing LDs with the WBTB + MILD technique.

4.3.12 Week 1 vs Week 2 dream recall measures

4.3.12.1 Average dream recall

A paired-samples t-test was used to determine whether there was a statistically significant difference between Week 1 average dream recall vs Week 2's average dream recall of dreams experienced post-WBTB + MILD technique (i.e., dreams experienced after performing WBTB + MILD). There was a statistically significant increase from Week 1 in average dream recall, $Z = -.473$, $p < .001$. This result suggests that practising WBTB + MILD affects dream recall positively.

4.3.12.2 Dream recall completeness for each dream title

Participants who wrote down dream titles for each dream that they could remember unlocked a question for each dream title which asked how complete their memory was of the dream (i.e., Fragmentary memory, Partial memory, Majority memory and Whole memory). A one-way repeated measures ANOVA was conducted to determine whether there was a statistically significant difference in dream recalled completeness of the last dream participants had before waking up and wrote a dream title for, over the course of the two weeks. There were no outliers and the data was normally distributed at each time point, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was met, as assessed by Mauchly's test of sphericity, $\chi2(2) = .903$, $p = .144$. There were significant changes in average memory completeness over time (Week 1, Week 2 Pre-WBTB+MILD and Post-WBTB+MILD), $F(2, 78) = 22.48$, $p < .001$, partial $\eta2 = .366$, with average dream memory completeness increasing from Week 1 ($M = 2.29$, $SD = .65$) to Week 2 Pre-WBTB+MILD ($M = 2.84$, $SD = .96$) to Post-WBTB+MILD ($M = 3.25$, $SD = .80$). Post hoc analysis with a Sidak adjustment revealed that average dream memory completeness was statistically significantly increased exponentially from Week 1 to Week 2 Pre-WBTB+MILD ($M = -.555$, 95% CI [-.911, -.199], $p = .001$), and from Week 1 to Week 2Post-WBTB+MILD ($M = -.961$, 95% CI [-

1.27,-.652], p < .001), as well as from Week 2 Pre-WBTB+MILD to Week 2 Post-WBTB+MILD (M = -.406, 95% CI [-.811, <0.0001], p = .050). Therefore, these results suggest that practising the RC + WBTB + MILD technique leads to an increase in how complete dream recollection is.

4.3.12.3 Dream Recall Amount (DRA) in Week 1 vs Week 2

Whereas the above question was only revealed for participants who assigned dream titles to the dreams they could remember, the DRA question was asked to all participants. A one-way repeated measures ANOVA was conducted to determine whether there was a statistically significant difference in DRA over the course of the two weeks. There were no outliers and the data was normally distributed at each time point, as assessed by boxplot and Shapiro-Wilk test (p > .05), respectively. Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated, p = .246. There were significant changes in DRA over time (Week 1, Week 2 Pre-WBTB+MILD and Post-WBTB+MILD), F(2, 100) = 49.87, p < .001, partial $\eta 2$ = .499, with average DRA decreasing from Week 1 (M = 3.26, SD = .71) to Week 2 Pre-WBTB+MILD (M = 2.12, SD =.94) and then increasing in Post-WBTB+MILD (M = 3.39, SD = .95). Post hoc analysis with a Sidak adjustment revealed that DRA was statistically significantly decreased from Week 1 to Week 2 Pre-WBTB+MILD (M = 1.145, 95% CI [.877, 1.413], p < .001) but did not differ from Post-WBTB+MILD, p = .198. This result suggest that setting an alarm to wake up in the middle of the night (to perform WBTB + MILD) leads to a decrease in dream memory completeness and that practising the WBTB + MILD did not lead to an increase in memory completeness when compared to Week 1's dream memory completeness. Thus, as the dream recall completeness (DRC) and DRA results differ, this is suggestive that the act of or the motivation of writing down dream titles may enhance DRA.

4.3.12.4 Average dream clarity in Week 2 pre-WBTB+MILD vs post-WBTB+MILD

Participants reported increased dream memory clarity post-WBTB+MILD (M = 2.31, SD = 1.18) than in pre-WBTB+MILD phase (M = 1.70, SD = .81) of Week 2, t (69) = -4.784, p < .001, suggesting that either the WBTB or the MILD technique, or both techniques contribute to increased dream memory clarity.

4.3.12.5 Does waking up from a dream increase chances of the WBTB + MILD technique at inducing LDs?

Aspy et al (2017) conducted a 2x2 chi-square test to investigate whether waking up from a dream when awoken from the alarm to perform the WBTB+ MILD (now referred to as "Woken from a dream pre-WBTB + MILD") resulted in a higher chance LDs. Aspy et al's (2017) "Woken from a dream pre-WBTB + MILD" question included five possible responses "Definitely Yes", "Probably Yes", "Might or might not", "Probably not" and "Definitely not". To perform 2x2 chi-square test he collapsed "Definitely Yes" and "Probably Yes" into a response of "Yes" and the two negative answers into a "No" response, while the "Might or might not" response was removed from the analysis.

In this study a 2 x 5 chi-square test of independence was attempted between reports of having been woken up from a dream by their alarm when it was time to perform the WBTB + MILD technique and experiencing an LD after performing the technique. The chi-square test was run for each day of Week 2. Aspy et al (2017) reports one overall test but it is uncertain how a 2x2 chi-square test could be performed on a longitudinal study with possible different types of responses each day. When it came to the sample which experienced lucid dreaming all expected cell frequencies in the responses confirming that participants had been awoken from a dream

when the alarm went off to perform the WBTB + MILD technique were not greater than five (also see graph x below for example). Even when collapsing "Definitely yes" and "Probably yes" responses into one answer ("Yes") of the "Woken from a dream pre-WBTB + MILD" variables, the number of cases did not meet the chi-square test requirement of five. Thus, chi-square table was used to increase response numbers as much as possible and a Fisher's exact test with a time limit of five minutes per test was performed due to response numbers being lower than five in some cases (Blalock, 1972). Results from fisher's exact test showcased that there was no difference in all days, $p > .05$, other than in day 3, $p = .020$. Specifically, in day 3, Fisher's Exact test revealed a statistically significant association between "Woken from a dream pre-WBTB + MILD" and whether participants experienced LDs or not after practising the WBTB + MILD technique, $p = .045$. There was a strong association between being awoken from a dream to perform the WBTB + MILD technique and whether participants subsequently experienced an LD, $\varphi = 0.545$, $p = .015$, (also see figure 4.2).

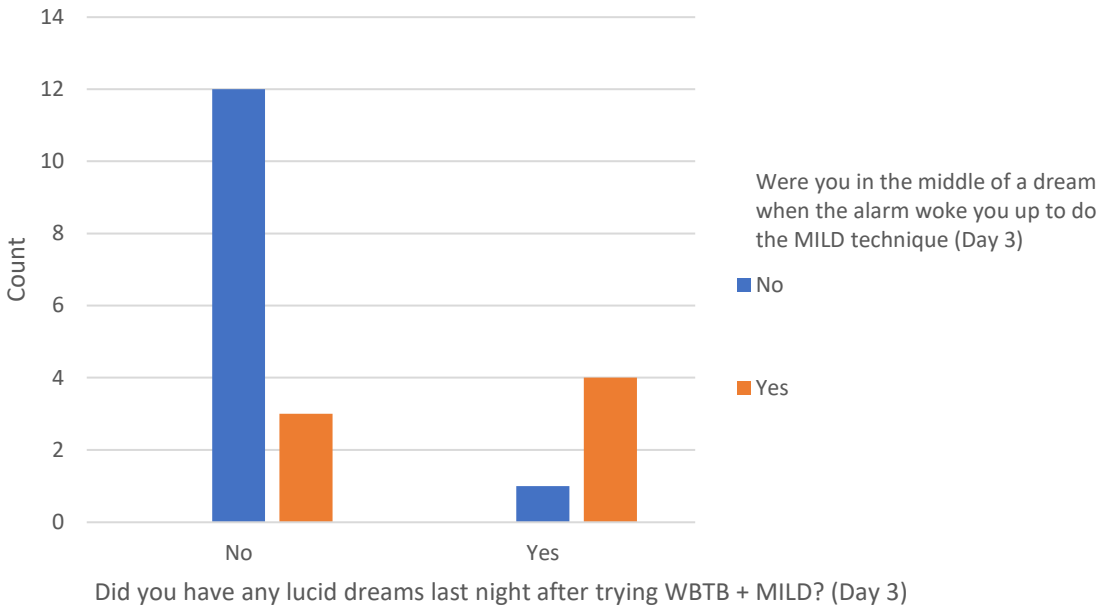

Figure 4.2 Day 3 of Week 2 participant responses to whether (a) they were awoken from a dream when they woke up to do the WBTB + MILD technique and (b) they had experienced a lucid dream after trying the WBTB + MILD technique.

Thus, the above result indicates that being awoken from a dream when having to perform the WBTB + MILD technique increased likelihood of experiencing an LD. However, due to the small sample size and the fact that the result was confined only in day 3, this result should be interpreted with caution.

4.3.12.6 Week 1 vs Week 2 DRD post-WBTB + MILD average dream recall difficulty

A paired-samples t-test was used to determine whether there was a statistically significant difference between Week 1 vs Week 2 dream recall difficulty. Paired-samples t-test revealed no significant differences, $p = .193$, showing that participants did not experience any change in difficulty of recalling dreams when practising the LD combination technique in Week 2.

4.3.12.7 Week 1 vs Week 2 sleep quality and morning tiredness.

A paired-samples t-test was used to determine whether there was any difference between Week 1 vs Week 2 sleep quality. There was no statistically significant difference in sleep quality between the two weeks, $p = .763$. A paired-samples t-test was used to determine whether there was a statistically significant difference between Week 1 vs Week 2 feelings of sleep deprivation and found no significant difference in morning tiredness between the two weeks, $p = .763$.

Thus, the overall outcome of these results suggests that practising the LD technique combination that was tested in this study does not affect perceived sleep quality and feelings of sleep restoration, replicating findings of Aspy et al (2017).

4.3.13 Use of sleep-affecting substances/medicine and Weeks 1 and 2 measures.

Participants who reported using sleep-affecting substances were compared against those who were not using any of the reported substances. Overall, 80 participants reported sleep-affecting substance use in the Week 1 sample and 14 participants in the Week 2 sample. No significant group differences were found in any of the two week measures, ps > .05. This suggests that sleep altering substance use was not a contributing factor in LD induction during the week of RC + WBTB + MILD practise.

4.3.14 Lucid dreaming skills (LUSK) differences between Week 2 Lucid Dreamers and Week 2 Normal Dreamers.

Week 2 Lucid Dreamers did not report having greater awareness (LUSK AWARENESS) or control abilities (LUSK CONTROL) assessed by LUSK in the pre-test questionnaire than the Week 2 normal dreamers, p > .05 Moreover, for Week 2 Lucid dreamers, there was no relationship between LUSK AWARENESS/CONTROL and the reported duration for which they were lucid, p > .05.

4.4 Discussion

The purpose of this two-week longitudinal study was two-fold: Firstly, to gain a better understanding of some of the retrospective evaluations in Chapter 3 in regards to interindividual differences in LDF; Secondly, to better understand the interindividual differences in the success of the RT + WBTB + MILD, method by improving upon various

aspects of technique protocol by Aspy et al (2017). The improvements to Aspy et al's (2017) protocol were:

1) To reformulate Aspy et al's (2017) pen and paper log entry-type questionnaires into an online study where participants could not consult previous entries. This was in order to control for possible memory effects confounds caused by reviewing past information (Gounden & Quaglino, 2018).

2) To add more screening questionnaires such as the FFMQ, PRMQ, and the general DQ (which were utilised in Chapter 5), as well as to add the LuCiD scale (Voss et al., 2012) to measure different factors of dream consciousness experienced during the two-week protocol. This was done to shed light in interindividual differences in DRF and LDF as well as to explain differences between Week 1 and Week 2; particularly differences between those who achieved lucid dreams in Week 2 and those who did not.

3) To add dream work practise in the form of noticing dream signs and noting them down in the appropriate dream sign categories developed by Levitan (1992) and to formulate this as part of the dream rehearsal aspect of the MILD technique. Also in line with LaBerge's recommendation from his book "Exploring the world of lucid dreaming" to perform a relaxation technique prior to performing before-bedtime LD induction techniques such as MILD and WILD (LaBerge & Rheingold, 1990), we included an audio guided progressive muscle relaxation script. This was then followed by an audio-guided MILD script which ensured a more uniform mental practise of the MILD technique across participants.

In order to discuss the results and their implications, we will begin by outlining and discussing general findings from the screening and Week 1 questionnaires that are unrelated to practising the RC + WBTB + MILD technique (see section 4.4.1). Subsequently, as the study was largely based on Aspy et al's (2017) protocol, we will outline and discuss the remaining results in three different realms: Novel findings, replicated findings and contrasting findings to that of Aspy et al (2017; (see sections 4.4.2, 4.4.3 & 4.4.4)

4.4.1 General findings from screening questionnaires and Week 1

High DRF is a key factor for increasing LDF as it has been shown repeatedly in the literature to be one of the highest correlating factors for LDF (Schredl & Erlacher, 2004). Thus, it was important to investigate how DRF and dream recall during the two weeks affects LD induction. Findings from the first week (where no LD techniques were attempted) showcased that participants who reported general high DRF tended to also report more dream recall days during Week 1. This result echoes results from previous studies which compared log-book sleep diary entries with general DRF (Aspy, 2016). It is worth noting that Aspy (2016) and Ribeiro, Gounden & Quaglino (2018), found that participants tend to underestimate DRF when compared to log-book DRF but this assumption could not be tested in our data as our DRF question was on a 8-point Likert scale and we did not ask participants to retrospectively estimate how many dreams were remembered upon waking in the past two weeks prior to the commencement of the study. Future longitudinal studies should include both questions to be able to compare retrospective and log-book baseline and intervention dream recall ability.

Participants with high general DRF were also able to recall more dream details during the baseline Week and had less difficulty in doing so. In addition, participants who estimated a lower percentage of fragmentary dream recall and higher majority or whole dream memory

recall in the past few months (*General DQ*) were also able to recall more dream details during the baseline week. These findings provide additional longitudinal support for the findings in Chapter 3 which reported a positive correlation between general DRF and general DQ.

During Week 1, participants who reported higher general DRF were also more likely to report higher insight into the fact that they were dreaming, more control of their dream actions and of the dream environment/plot and that memory and thought processes were more similar to waking experience (as ascertained by the LuCiD scale). Even when looking only into participants who did not lucid dream in Week 1 to avoid inflation of LuCiD factors caused by LDs, higher ability to control dreams (control of dream scenario can occur without strong insight into the fact that one is dreaming) and higher thought processes were again found to be positively correlated with demonstrating that higher DRF is correlated with higher dream consciousness processes. In addition, similar correlations between LDF and the LuCiD scale to the ones with DRF and the LuCiD scale, were also found, highlighting again how interlinked LDF and DRF are. Furthermore, the ability to recall a greater amount of dream details (DRA) in Week 1 was linked to all LuCiD factors. Past neuroimaging research by Eichenlaub et al. (2014) on DRF shows that higher regional cerebral flow in the media-prefrontal cortex (mPFC) and temporoparietal junction (TPJ) in both waking (resting state) and sleep (NREM3 and REM) in high DRF participants when compared to low DRF participants. These same areas implicated in DRF are also implicated in lucid dreaming (Dresler et al., 2012; Voss & Voss, 2014).

Surprisingly, we did not find significant any significant relationship between PRMQ and any of Week 1's log-book questions including average LD induction rate, DRA, LuCiD scale etc (nor in Week 2 log-books). This is surprising because findings in this chapter and chapter 3 show that higher cognitive ability is correlated with higher DRF and LDF related questions.

Specifically, in Chapter 3, we found a significant, although small relationship, between retro/prospective memory ability and LDF. As the previous thesis chapter (in chapter 3) included screening responses from this study we expected higher retro/prospective memory ability to be correlated with a higher average LD induction rate score, average dream recall etc. Regarding mindfulness findings, all FFMQ factors except "Acting with Awareness" were found to be correlated with a variety of LuCiD factors, MEMORY, THOUGHT and POS/NEGATIVE EMOTIONS in Week 1. Thus, our supposition here is that the LuCiD factors MEMORY and THOUGHT are more related to experiencing higher level of dream consciousness (i.e., more akin to that of waking consciousness) than the POS/NEGATIVE EMOTION factors of the LuCiD scale. This is because the POS/NEGATIVE EMOTION LuCiD factors are constructed entirely by questions relating to the intensity of the positive or negative emotions experienced whilst dreaming and it is the LuCiD factor REALISM that investigates whether the emotional tone of the dream or the emotional responses whilst dreaming are similar to how one is or how one would respond in waking consciousness. We consider two possibilities for the positive and negative correlations between mindfulness and intensity of positive and negative emotions experienced whilst dreaming:

1) The correlation between LuCiD factors relating to the intensity of the emotional experience and mindfulness have more to do with how mindfulness improves emotional responses and mood in waking (Rodrigues, Nardi & Levitan, 2017) and how this spills over in dreams and vice versa, according to the 'Continuity Hypothesis' (Schredl & Rheinhard, 2010).

2) The fact that we also found positive correlations between negative and positive dream emotion intensity and all other LuCiD factors is suggestive of the idea that emotional

dreams increase cortical activation (Sikka, Revonsuo, Noreika & Valli, 2019) which can shift sleeping consciousness closer to that of waking. In turn, this increase in emotional intensity may increase activation in the frontotemporal regions of the brain that are associated with experience of LD (Dresler et al., 2012; Voss, Holzmann, Tuin & Hobson, 2009).

4.4.2 Novel findings from Aspy et al (2017)

While there were significant positive correlations between LuCiD factors and FFMQ factors MEMORY and THOUGHT in dreams experienced during Week 1, there were no group differences in FFMQ scores between participants who lucid dreamed in Week 2 and those who didn't. This discrepancy is likely due to the decreased sample size that went on to complete at least one day of Week 2 which was less than three times the sample that completed only Week 1 entries. In addition, the group that went on to Week 2 had higher "Acting with Awareness", "Mindful describe" and "Non-Judging" FFMQ scores than the group which only completed days in Week 1. Moreover, when including only participants who went on to Week 2, the LuCiD factor NEGATIVE EMOTION was negatively correlated with FFMQ factor "Acting with Awareness" while the LuCiD factor REALISM was positively correlated with FFMQ factor "Describe".

The difference in mindfulness between participants who went on to Week 2 is possibly due to the fact that mindfulness has been associated with various aspects of motivational ability (Levesque & Warren Brown, 2007; Ruffault, Bernier, Juge & Fournier, 2016). Thus, although email reminders were sent out each day to remind participants to complete the daily questionnaires and automatic motivational emails encouraging participants to continue with

the study that gave out different messages when participants reported lucid dreaming or not, this was not enough to stop high attrition rates.

Overall, 41.07% of the 65 Week 2 participants who reported remembering having dreamt at least once in Week 2, experienced lucid dreaming at least once. The present study's overall LD induction success percentage is thus lower than the one reported in Aspy et al. (2017) who reported a 53.2% LD success. The present study's overall mean average LD induction rate score in week 2 was 8.89% which was also considerably lower than the 17.4% mean average Week 2 LDF score reported in Aspy et al. (2017). While differences in LD induction rates were found between the present study and Aspy et al (2017), the present study's modified LD-inducing technique cannot be interpreted as inferior, as Aspy et al's (2017) sample included only participants who completed the full two-week study. As we found out that participants who lucid dreamed in Week 2 had completed more Week 2 days than those who didn't we surmise that it is highly likely that we would have achieve similar or higher LD induction rates than Aspy et al's (2017) RC + WBTB + MILD protocol, had a larger sample of participants completed the full two-week protocol.

Just like in the paper by Voss et al. (2013) where the LuCiD scale was developed, we also found that LuCiD factors INSIGHT, CONTROL and DISSOCIATION are most associated with lucid dreaming. Furthermore, participants who lucid dreamed in Week 2 scored higher in LuCiD factors INSIGHT and THOUGHT in Week 1 and had higher general DRF and LDF scores. Thus, this finding demonstrates that baseline cognitive and metacognitive ability in dreams is likely to make it easier to experience LDs when practising cognitive LD induction techniques.

Surprisingly, we did not find mindfulness and retro/prospective ability differences between people who lucid dreamed and those who didn't. Thus, the long-held belief that MILD success rests on the ability to engage prospective memory processes is put in question.

4.4.3 Replicated findings from Aspy et al. (2017)

Our study had several replicated findings from Aspy et al (2017). General prior experience with LD techniques and frequency of practise was not found to be significantly different between the group of participants who lucid dreamed and those who didn't in Week 2. We also looked into specific experience with the RC + WBTB + MILD technique; specifically, whether they had tried the technique before, how many times they estimated they tried it and their perceived percentage success rate with the technique, but we didn't find any significant group differences. Thus, these results indicate that prior experience with LD techniques is not a pre-requisite of LD induction success, suggesting that the RC + WBTB + MILD is effective when practised in a period and that it is appropriate for participants without prior LD technique knowledge or training. Likewise with Aspy et al's (2017) results, motivation and focus on the technique are not factors for inducing LDs with the WBTB + MILD technique. Moreover, just like Aspy et al's (2017) findings, we saw that there was a significant increase in LDs from Week 1 to Week 2, suggesting that this combination of techniques is effective at inducing LDs. Similar to Aspy et al's (2017) results, participants in the current study experienced an increased dream recall ability from Week 1. Specifically, on average participants were more likely to report dreaming post-WBTB + MILD and were able to remember more dream details than in Week 1 or Week 2 pre-WBTB + MILD. Moreover, those who experienced LDs in Week 2 had higher average DRA. These results showcase that either WBTB or MILD practise or both results in heightened dream recall ability. We propose that the WBTB method plays the sole

or most significant role in this effect as it has been suggested that brief inter-night awakenings cause increased cortical activation that subsequently remains (to some extent) when going back to sleep (Wamsley, Hirota, Tucker, Smith, & Antrobus, 2007; Smith, & Blagrove, 2015). Thus, the WBTB technique is thought to lead to higher dream recall ability and increase the chance of experiencing LDs (Smith, & Blagrove, 2015).

In addition, similarly with Aspy et al. (2017) who found that the 'RC only' group had the worst LD induction rate by far, we also found that the RC technique alone is much less effective than when it is combined with the 'WBTB + MILD' technique. While we didn't test different groups of different combinations of the RC, WBTB and MILD techniques, as in Aspy et al. (2017), we decided to attribute LDs reported upon waking up before performing the WBTB + MILD technique to the RC technique and only five LDs had occurred in total. Furthermore, consistent with Aspy et al. (2017), the number of RCs performed did not seem to impact LD induction rates. However, although Aspy et al. (2017) found no relationship between number of RCs performed in the 'RC only' and 'RC + WBTB + MILD' group, they did find that in the 'RC + WBTB' group, the number of RCs did matter. The authors attribute this difference to a primacy effect, as the 'RC + WBTB' group was asked to perform an RC before going to bed while the 'RC + WBTB + MILD' group. In general, RC is considered to be more effective when combined with other LD techniques (Purcell, 1988; Paulsson & Parker, 2006; Aspy et al., 2017).

Finally, we somewhat replicated the Aspy et al. (2017) conclusion that LD was more likely when participants had awoken from a dream when having to perform the WBTB + MILD technique, but this finding was limited to only day 3 of Week 2. Due to the small sample size and the significant variance in the number of completed Week 2 days between participants, this

result should be interpreted with caution. We consider it plausible that had all our analysed sample completed the same amount of days and hence we had been able to run the exact statistical test that Aspy et al (2017) had ran, we would have found the same result as Aspy et al (2017). We postulate that the reason behind the increase in LD likelihood when awoken from a dream is due to the REM rebound effect causing longer REM periods as well as a shorter REM latency (Feriante & Singh, 2020). We hypothesise that the REM rebound effect benefits LDs in two ways. Firstly, the time between LD technique practise and dreaming is shortened, likely causing a higher memory retention of performing the MILD technique (specifically the 'intention' aspect of the technique) upon reaching REM sleep. Secondly the REM rebound effect should cause the brain to reach REM sleep faster at a higher cortical activation status, which (as mentioned above) is conducive to achieving LD (Dresler et al., 2012).

4.4.4 Contrasting findings from Aspy et al. (2017)

Not all results were replicated from Aspy et al (2017). For example, Aspy et al (2017) found that that the smaller the SOL, while practising MILD, the more likely participants were to report LDs. However, we did not replicate this finding, as SOL was not different between those who lucid dreamed and those who did not. This discrepancy may due to the fact that all participants had to stay awake for a few minutes to complete the pre-WBTB+MILD questionnaire upon waking up to perform MILD and then go through a the guided relaxation and MILD audio tape which lasted ten minutes and thirty one seconds.

While we replicated the Aspy et al (2017) finding of no change in perceived sleep quality, we did not find that participants who lucid dreamed reported being less tired in the morning. Instead, we found that perceived sleep quality and morning tiredness did not change from Week

1 to Week 2 and were not different between those who lucid dreamed and those who did not. Thus, our results back previous finding that practising the lucid dream techniques either does not negatively affect or improves reported sleep quality and next morning affect (Aspy et al., 2017; Schredl, Dyck & Kühnel, 2020; Ribeiro, Gounden, & Véronique Quaglino, 2020; Carr et al., 2020). We postulate that the reduction in morning tiredness in LD participants may be due to a more gradual shift towards wakefulness caused by an increase in cortical activation. Consequently, this gradual shift towards wakefulness may lead to reduced feelings of sleep inertia upon waking up.

4.4.5 Study strengths, limitations and directions for future research

We consider the inclusion of the many pre-test questionnaires and the inclusion of the LuCiD scale in the Week 1 and 2 logbooks to be a significant step towards understanding the interindividual differences in the success of one of the most powerful and relatively easy combinations of cognitive LD induction techniques. An example of this is that the inclusion of the LuCiD scale showcased shifts in dream consciousness towards waking consciousness when practising the RC + WBTB + MILD technique even in those who did not experience a lucid dream during Week 2. In addition, the inclusion of progressive relaxation and the addition of 'dream signs' is more closely in line with LaBerge's original suggestions, who is the creator of all three techniques. Moreover, we consider the inclusion of the audio-guided MILD tape to have allowed for an additional control in how participants executed the MILD technique steps. One of the limitations of our study was that although the sample size was slightly higher than Aspy et al's (2017) RC + WBTB + MILD group, our sample contained a large number of incomplete Week 2 day entries. Thus, it remains to be seen how Week 2 LD induction rates

might have changed had we had a sufficiently large sample that completed all seven days of Week 2.

Regarding attrition rates, a total of 311 participants completed at least one day of Week 1 but only 91 participants went on to complete at least one day of Week, while only 15 participants completed the full Week 2. In the future, other types of motivational technique should be employed to improve intrinsic and extrinsic motivation of participants to fully complete the study and keep attrition rates at a minimum. Examples of extrinsic motivation that could be used in future studies are participant payment and prize draws whilst intrinsic motivation examples could be to mention the documented well-being benefits and applications of lucid dreaming (Legault, 2016).

We must also consider the possibility of sampling technique confounds, as the participants we recruited were mostly online users of LD-related forums, which meant that our sample was highly interested in lucid dreaming. Hence, intrinsic motivation to experience learn more about lucid dreaming may affect LD induction rates. For example, when compared to the general population, our sample might score significantly higher in Openness to Experience factor of the Big Five Personality Test, a factor positively correlated with LDF (Hess, Schredl & Goritz, 2016).

In terms of future research, it would be useful to extend the current findings by examining possible improvements to all three techniques used in the study. When it comes to the RC technique, future studies should look into how different times of day of RC practise may impact LD induction success. While Aspy et al (2017), found that the number of RCs performed did not seem to impact LD induction rates in the RC + WBTB + MILD technique, they did find

that in the 'RC + WBTB' group, the number of RCs did matter. The authors attributed this finding to a recency effect, as they had asked participants of the 'RC + WBTB' group to practise RCs after waking up in the middle of the night and before going to sleep again. Thus, their findings suggest that the time RC are performed is crucial. Future studies could look into not only whether LD induction through the RC method is affected by the recency effect but also whether primacy has any effect. Perhaps it is beneficial to perform half of RCs in the morning and the rest before going to sleep after having awoken in the middle of night to perform the WBTB technique.

In terms of future research, it would also be useful to extend the current findings by examining different times of interrupting a REM period to perform the WBTB + MILD technique. Our current findings, as well as those of Aspy et al (2017), suggest that interrupting REM periods or periods where participants remember being awoken from having dreamt (in order to perform the WBTB + MILD technique), improves likelihood of LD. Future studies could also look into the effect of depriving REM sleep throughout the early cycles of sleep (through forced awakenings) and then seeing whether allowing the REM rebound effect to happen at the later hours of the night has any positive effect at inducing LDs.

Future studies investigating cognitive LD induction techniques could accrue large sample sizes and ensure stronger ecological validity through the use of small sleep wearable EEG technologies given to participants to use at home.

4.4.6 Conclusion

In summary, our research replicated several findings of Aspy et al (2017) while at the same time further enhanced our understanding of interindividual differences in lucid dream induction

success using the RC + WBTB + MILD technique. Among many findings, the study showcased how dream consciousness shifts closer to waking consciousness when practising this combination of techniques regardless of whether LDs are experienced. In addition, we demonstrated how mindfulness impacts several dream consciousness factors. Therefore, we highly recommend the inclusion of the LuCiD scale (Voss et al., 2013) in studies in order to investigate shifts in dream consciousness that are not captured through binary response questions which ask whether one experienced LDs or not. Despite significant attrition rates throughout Week 2, the relatively high LD induction rate showcases that this combination of LD induction techniques is effective at inducing LDs. We hope that the current study will stimulate further investigation of the RC + WBTB + MILD technique and of other types of cognitive LD induction techniques, particularly with the addition of electroencephalographic equipment and data. Future studies should aim to use machine learning algorithms to predict whether one is likely to experience LD on the first time of attempting the technique (e.g., in a sleep lab setting) based on answers given in screening questionnaires and from baseline week entries. Successfully predicting induction of LD will enhance participant selection for LD studies that are not concerned with induction, especially when experienced/frequent lucid dreamers are not available.

CHAPTER 5

"Achilles, you are dreaming!" Investigating the effect of receiving personalised audio that is adjusted to individual awakening thresholds: A machine learning approach

5.1 INTRODUCTION

LD has shown potential in addressing scientific questions regarding how consciousness is formed (Voss & Voss 2014) and understanding insight impairment in psychiatric conditions (reviewed in Baird, Mota-Rolim & Dresler, 2019). LD has also been demonstrated to have therapeutic applications in Recurrent Nightmare Disorder (RND), Post-Traumatic Stress Disorder (PTSD), Insomnia and some mood disorders (reviewed in Mota-Rolim & Dresler, 2019). Furthermore, LD can improve motor skills and could potentially be used in sports training and motor rehabilitation (Schädlich & Erlacher, D, 2018). However, in order to access the potential benefits of LD on health and wellbeing and to advance consciousness and cognitive research, it is necessary for research to be done on how to reliably and easily induce LD. As outlined in Chapter 2, various LD induction techniques have been proposed and tested such as cognitive, external stimulation and psychopharmalogical approaches (reviewed in Stumbrys, Schädlich & Schredl, 2012). Chapter 3 investigated the combined effectiveness of the cognitive LD induction techniques RC + WBTB + MILD. While this combination of the above LD techniques produced an average LD induction rate of 41.07% over a period of one week of attempts, we surmise that there is a large room for improvement in LD induction rates. We are still a long way away from a method where LDs can be achieved reliably with minimal to no practise every or almost every night and we hypothesise that such a feat is unlikely to be achieved through the use of cognitive LD induction techniques alone.

Pertinent to this chapter is the advancement of external stimulation techniques, which present visual, tactile and/or audio stimuli, during REM sleep [Stumbrys, Schädlich & Schredl, 2012, Appel, Pipa & Dresler, 2017). Such stimuli tend to become incorporated into the dream and can trigger LD by suggesting to the dreamer that they are dreaming (e.g., through a flash of light appearing in the dream scenario). Micro-arousals (minor and extremely short-lived unconscious awakenings) caused by the stimuli are thought to be the mode through which the stimuli become incorporated into the dream content (Solomonova & Carr, 2019). Following such a micro-arousal, the on-going dream continues, and the stimulus becomes re-contextualised into the ongoing dream narrative through the process of multisensory integration (Solomonova & Carr, 2019). Compared to other LD induction techniques, we believe that external stimulation (ES) techniques have the largest capacity for experimental control, the least unwanted impact on sleep physiology and no known side-effects that, for example, a pharmacological intervention may have.

However, to date, ES techniques have some challenges and varying rates of success that can range from 9% to 87% (Stumbrys, Schädlich & Schredl, 2012, Appel, Pipa & Dresler, 2017; Solomonova & Carr, 2019). Often, such stimuli lead to awakenings or are not incorporated. This can be attributed to the individual variability of stimulus awakening thresholds (SATs), as each individual attenuates external stimuli in sleep differently (Stumbrys Erlacher, Schädlich & Schredl, 2012;Appel, Pipa & Dresler, 2017; Solomonova & Carr, 2019; Busby, Mercier & Pivik, 1994; Zepelin, McDonald & Zammit, 1984; Vallat et al., 2017; Ruby et al., 2013; Perrin, García-Larrea, Mauguière, & Bastuji, 1999; Eichenlaub, Bertrand, Morlet & Ruby, 2014; Portas et al., 2000). Therefore, stimuli may be too intense (leading to awakenings) or too weak to be incorporated (Appel, Pipa & Dresler, 2017). On occasion, when stimuli are successfully incorporated into dream content, the dreaming brain tends to confabulate reasons

about their appearance and contextualises them in a way that does not alert the dreamer that they are indeed dreaming (Solomonova & Carr, 2019). For example, flashes to the eyes can make a dream room's lights go on and off and excused by the dreamer as a malfunctioning of the light bulb.

The purpose of this chapter will be to develop a novel theoretical and technical framework which utilises machine learning algorithms in order to enhance auditory stimuli incorporation into dream content. We surmise that external stimulation techniques used either in isolation or combined with cognitive techniques are the most promising avenue of inducing lucid dreaming reliably and easily. Particularly, we hypothesise that this can be in part achieved through the development of a Machine Learning (ML) based predictive model of stimulus awakening thresholds (SATs). Central to the proposed Individualised Auditory Stimulation (IAS) technique is the successful prediction of SATs using Machine Learning (ML) algorithms, in order to present auditory stimuli as loud as possible and to repeat the stimuli as frequently as possible, without causing any awakenings. To achieve this, the ML algorithm needs to be trained on behavioural and physiological data that is acquired prior to any stimulation in order for the appropriate stimulus properties to be adjusted accordingly and presented to the individual whilst they are dreaming.

Support for the development of an ML predictive model of SATs as a means to enhance LD induction rates comes from past research outlined in chapter 2, which displayed favourable results when attempts were made to adjust stimulus properties to the individual. Examples include adjusting stimulus properties in pre-test nights by gradually increasing stimulus properties until individual SATs were found (e.g., LaBerge, Levitan, Rich, & Dement, 1988) or in studies where stimulus properties are adjusted during the test night (e.g., Reis, 1989;

Schädlich & Erlacher, 2014; Erlacher et al., 2020). However, both these methods have several drawbacks. Firstly, adjusting stimulus properties in pre-test nights significantly delays data collection, increases cost and burdens both the participant and the experimenter. Secondly, SATs may not be consistent between nights as they can be affected by multiple variables such as time spent awake, tiredness and ingesting specific medicines/drugs/supplements (Bruck, 2001). Thirdly, adjusting stimulus properties during the test night until SATs are reached introduces a set of new variables that may not only subsequently affect SATs but also LD induction. Specifically, intra-night awakenings could increase or decrease subsequent SATs and as demonstrated by studies on the WBTB method, intra-night awakenings may cause LDs in themselves (Stumbrys et al., 2012; Smith & Blagrove, 2015).

The present study will provide the building blocks of the proposed IAS technique by investigating the effect of adjusting stimulus intensity to an individual's auditory awakening threshold (AAT) and by building a database for the ML to train on in order to be able to predict individual AATs in future studies with high accuracy. This will be achieved by gradually increasing the volume/intensity of an auditory stimulus by small increments in intensity during REM sleep until it reaches one's AAT. Subsequently, upon awakening from the stimulus, the intensity of the stimulus will be adjusted to the individual, 10% lower than the intensity that woke them up. Following this, the participant will be asked to go back to sleep and the stimulus will be presented again during REM sleep and will increase back up again in smaller increments towards the intensity that woke the participant up. This will be done to investigate whether AATs are stable following a brief intra-night awakening.

Another innovative aspect in this study's methodology is the inclusion of an auditory stimulus that will be played during REM sleep that will comprise of a computerised voice which will

call out participants' first name and inform them that they were dreaming (e.g., "Achilleas, you are dreaming!"). The rationale for using auditory speech stimulation in lieu of other stimuli used in previous research (e.g., light flashes, auditory beeps, tactile stimulation etc) is that we hypothesise that it will increase the semantic quality of the stimulus and make it less likely that participants will excuse away the stimulus. This is because, as outlined in Chapter 2, past research has shown that the presentation of first names during sleep increases brain activation in the frontotemporal regions of the brain (Vallat et al., 2017; Ruby et al., 2013; Perrin, García-Larrea, Mauguière & Bastuji, 1999; Eichenlaub, Bertrand, Morlet & Ruby, 2014; Portas et al., 2000) which are key areas for LD (Voss, Holzmann, Tuin & Hobson, 2009; Dresler et al., 2012). To decrease the likelihood that participants confabulate reasons about the incorporation of our auditory stimulus, participants will be trained during wake to perform a reality check (RC) whenever they hear the stimulus. Thus, we have modified the Targeted Lucidity Reactivation (TLR) paradigm that was used in Carr et al. (2020), where participants were trained to imagine becoming lucid whenever they heard the auditory or visual stimulus. We predict that conditioning the performing of a procedural task (reality check) upon perception of an auditory stimulus is likely to have a greater effect.

The study will take a data-driven approach; hence we will extract all types of sleep features from the hypnogram and the sleep EEG that are available through the YASA software described in chapter 1. In addition, we hypothesise the following:

1) Participants who experience more micro-awakenings (prior to any stimulation) will have lower AATs.

2) Participants with less deep sleep and decreased SWA features (e.g., slope, amplitude) will have lower AAT.

3) Participants with a higher amount of REMs will have lower AAT, as that would be an indication of lower phasic REM sleep, as phasic REM sleep exhibits higher AAT than tonic REM (Ermis, Krakow & Voss, 2010).

4) Participants who have been awake for longer since their last sleeping episode will exhibit higher AAT, as ascertained by studies of sleep deprivation (Hubbard et al., 2020; Dijk, Beersma & Daan, 1997; Dijk et al., 1990; Franken, Chollet & Tafti, 2001; Jones, Vyazovskiy, Cirelli, Tononi & Benca, 2008; Martinez-Gonzalez, Lesku & Rattenbor, 2008; Franken, Tobler & Borbely, 1991)

5.2 METHODS

5.2.1 Participants

In total 98 participants completed the screening questionnaire that was sent out through the Psy-Vol system. Out of the screening sample, 32 healthy participants (13 males, 19 females), without prior physical and mental health issues and who had reported not taking any sleep affecting medications and substances were selected to take part.

5.2.2 Apparatus

Hypnodyne Zmax (http://hypnodynecorp.com/), which was described in Chapter 1 was used in order to record EEG activity, heart rate (PPG) temperature, room illumination and noise levels.

5.2.3 Materials

5.2.3.1 Screening questionnaire

Demographics questions included age, gender and occupation. Participants were provided with a list of sleep affecting substances/medications and asked whether they would be taking any of them during the two-night protocol ("Yes", "No", "Prefer not to say"). The list included medications such as anti-arrhythmics, beta blockers, clonidine, corticosteroids, diuretics, medications containing alcohol or caffeine, nicotine replacement products, antihistamines, antidepressants, sympathomimetic stimulants, theophylline, thyroid hormone and illegal substances such as THC, Cocaine, Heroin, MDMA, LSD and psychoactive mushrooms.

Participants were asked if they had ever had symptoms of, been clinically diagnosed, or received treatment for a mental disorder. The list included anxiety (including generalised anxiety, panic or phobic disorder), depression (including major depression and dysthymia), alcohol or other substance abuse or addiction, schizophrenia (or other psychotic disorder), eating disorder (including anorexia nervosa and bulimia), manic depressive illness (bipolar disorder), Post Traumatic Stress Disorder (PTSD), stress, sleeplessness, chronic tiredness, and Attention Deficit or Hyperactivity Disorder (ADD/ADHD).

Dream Recall Frequency (DRF) was measured through a 7-point scale (coded as 0 = never, 1 = less than once a month, 2 = about once a month, 3 = about 2 to 3 times a month, 4 = about once a week, 5 = several times a week, 6 = almost every morning). To elucidate how complete their dream memory had been in the past several months, a modified question was used from Aspy et al. (2017). Participants were asked to estimate a percentage of how complete their dream memory was in the days where they had woken up remembering that they had dreamt

the night before (in the past several months). The choices were as follows: 1) Fragmentary (F) - “You recall some content (such as a single scene or an isolated image). But not enough to provide any “flow” in the narrative. There are no transitions from one scene or event to the next”; 2) Partial (P) - “You recall enough content for there to be some “flow” in the narrative from one scene or event to the next. However, you’re pretty sure that most of the dream has been forgotten”; 3) Majority (M) - “You recall a substantial amount and you’re pretty sure you can recall at least half of the dream. However, there are frustrating gaps indicating that a significant amount is still missing”; 4) Whole (W) - “Fairly complete recall of the dream without any frustrating gaps in your memory of what happened (although the beginning of the dream and some details might still be missing)”. The question had a “constant sum” format, where the total percentage given in the categories had to amount to 100%.

Lucid Dream Frequency (LDF) was measured using an eight-point rating scale (“How often do you experience so-called lucid dreams?”: 0 = never, 1 = less than once a year, 2 = About once a year, 3 = about two to four times a year, 4 = about once a month, 5 = two to three times a month, 6 = about once a week, 7 = several times a week). The following definition for lucid dreams was given: “In a lucid dream, one is aware that one is dreaming during the dream. Thus, it is possible to wake up deliberately, or to influence the action of the dream actively, or to observe the course of the dream passively.” Participants who chose any option other than “Never” in the LDF question were asked to indicate (or estimate) how many lucid dreams they had experienced in total, and to indicate (or estimate) their lucid dream age onset (i.e., how old they were when they had their first lucid dream).

To ascertain various aspects of previous lucid dream technique practice, participants were asked if they had ever tried to have lucid dreams by learning and the practising a lucid dream

technique and how often they had practised a lucid dreaming technique in the past several months (0 = Never, 1 = Less than once a month, 2 = About once a month, 3 = Two or three times a month, 4 = About once a week, 5 = Several times a week, 6 = Almost every morning). To look more closely into what techniques participants had practised before, they were provided with a descriptor list of popular lucid dream induction techniques (from the scientific literature and online) to choose from (MILD; Mnemonic Induced Lucid Dream, WILD; Wake Initiated Lucid Dream; WBTB; Wake Back to Bed, VILD; Visual Incubation of Lucid Dreams, CAT; Cycle Adjustment Technique, RC; Reality Checks, ADA; All Day Awareness, Autosuggestion, Drug Applications, Binaural beats and other sounds, Stimuli devices, Other). A 5-point scale was used to elucidate how many of their lucid dreams happened spontaneously versus induced through a technique: 1 = "All my lucid dreams occurred spontaneously (without using any techniques)"; 2 = "Most of my lucid dreams were spontaneous, but some lucid dreams were deliberately induced (by using some lucid dream induction technique)"; 3 = "About half of my lucid dreams were spontaneous and the other half were deliberately induced"; 4 = "Most of my lucid dreams were deliberately induced, but some lucid dreams also occurred spontaneously"; 5 = "All my lucid dreams were deliberately induced").

The final screening questionnaire given to them was the Lucid Dream Skills questionnaire (LUSK; Schredl, Rieger, Goritz, 2018). The LUSK questionnaire measures inter-individual differences in lucid dreaming skills. LUSK is a 10-item questionnaire which enquires participants to estimate the frequency of awareness and control skills exhibited in lucid dreams, using a 5-point response scale (0 = In none, 1 = In a quarter, 2 = In half, 3 = In three quarters, 4 = In all), over two factors: Awareness/Perception (e.g., " …were you able to keep your awareness for a satisfying period of time?") and Control (e.g., " … were you able to deliberately

shape your environment, e.g., change landscapes/surroundings, let persons/characters appear or disappear?").

5.2.3.2 Two Night post-test questionnaire

This questionnaire was completed by the participants upon waking from the stimuli. They were asked if, upon awakening, they remember having dreamt at all ("Upon awakening, do you remember having dreamt at all?"). Subsequently, they were asked to make up brief titles of the dreams they experienced and to provide how complete their memory was for each dream that was remembered. Dream memory was attained through a categorical retrospective dream memory question which asked how complete their day of testing dream memory was (Aspy et al., 2017). The categories were the same as in the screening questionnaire (Fragmentary, Partial, Majority, Whole), but only one option could be selected for each dream remembered. They were also asked how hard it was for them Subsequently, participants were asked if they had any lucid dreams and for how long they estimated that they lasted.

They were then asked whether they had performed the reality check in their dreams and whether they performed it upon waking up from the stimuli and/or when awoken naturally. Participants were then asked to describe what happened in their dream when they performed the reality check.

Two stimuli dream incorporation questions were included in the questionnaire. The first question asked whether the stimuli were incorporated in any way and provided five examples of stimulus incorporation (Unchanged incorporations - The audio stimulus was the same in the dream as it does when the wearer is awake. For example: "I heard "my name, you are dreaming" just like how I heard it when I was awake during the training phase'*;* Incorporations as dream

narrative – *The auditory stimulus becomes part of the dream imagery. For example: "In my dream, a person in front of me told me that I am dreaming." or "The radio announced that I was dreaming!";* The second question asked participants to provide a brief description of how the stimuli was incorporated into the dream content. Participants were also asked whether they dreamt about the study and whether that prompted them to realise that they were dreaming. They were also asked whether they had done the predetermined eye-signal whilst they were dreaming. Finally, participants were asked how tired they felt upon waking up.

5.2.4 Procedure

5.2.4.1 Consent, briefing & Pre-sleep Questionnaire phase

Participants arrived at the Psychology sleep lab at 10pm. There, participants were briefed about the study protocol and completed the Pre-sleep Questionnaire. Participants were then informed that the study should start the latest at thirty minutes after midnight or earlier if they felt adequately sleepy and ready for bed.

5.2.4.2 Resting state EEG phase

Once participants were ready to start the experiment, they were instructed to lie in bed with eyes closed and to try not to move and wait for auditory instructions. Experimenter turned off the lights and started recording their resting state EEG for 1.5 minutes.

5.2.4.3 Phase 1: Training the RC response

After resting state EEG was recorded participants received auditory instructions that informed them that in the next ten minutes they would be receiving an auditory stimulus that will call out their name and inform them that they are dreaming. Upon hearing the stimulus participants were told question whether they are dreaming and to perform a reality check by pinching their nose closed and attempting to breathe through it. Participants then performed reality checks (a total of ten reality checks) for the next ten minutes in response to the reality check stimulus. The training stimulus was played at approximately 39dB, i.e., the starting stimulus intensity that would be played during REM. Auditory instructions resumed at the end of the training phase to inform them that they would be receiving the reality stimulus again while they were sleeping and that it will gradually increase in volume until it wakes them up. They were instructed to perform a reality check whenever they woke up regardless if they heard the reality check stimulus or not and afterwards to press any of the three black buttons located at the top side of ZMax. They were told upon pressing the black button that the speakers would inform them whether they were awoken naturally or if they woke up from the stimulus. If the instructions informed them that they woke up naturally they were instructed to go back to sleep. This procedure was done in order to prevent 'false awakenings': vivid and convincing dreams about awakening from sleep. If the audio confirmed that they were woken up from the stimulus, they were told to complete 'Questionnaire 1' (Calibration Phase Questionnaire) on the iPad located next to the bed and once they were ready to continue with the experiment to press any of the three black buttons again to continue with the rest of the experiment. Before informing participants that they could now sleep, they were told that if they became lucid they should do the following sharp eye movement pattern in quick succession: left-right-left-right. Participants were told to practise these pre-agreed eye movements (PAEM) once, following a beep sound.

5.2.4.4 Phase 1: Stimulus Calibration

After participants were prompted by the auditory beep to practise the PAEM, they were then told that they could go to sleep. Participants then went to sleep and ZMax started detecting REM phases of sleep three hours from the start of the experiment (resting state EEG phase). Following a thirty second REM epoch the reality check stimulus was immediately played through the speakers, first at 5% intensity (software volume level value which equalled to approximately 39 dBA) and increased 5% (approximately .6 dBA) for every subsequent REM epoch until it reached 20% (approximately 40.6 dB). After 20% stimulus intensity, the reality check stimulus increased by 10% (approximately 1.2 dB) for each detected REM epoch. As per the training phase 1 instructions, whenever the participants woke up, they performed the reality check and pressed any of three ZMax black buttons. A pre-recorded message then informed them whether they were awoken naturally or from the stimulus. The natural awakening message was played when there were at least three minutes gap or more since the last time the reality check stimulus was played over the speakers. The three-minute minimum gap was chosen to allow enough time for participants to come out of any potential sleep inertia and to press the button to respond to waking up from the RC stimulus.

5.2.4.5 Phase 2: Training the RC response

When participants were informed that the cause of awakening was due to the stimulus, they were then asked to complete the questionnaire and to press any of the black buttons to continue with the experiment. Once participants completed “Questionnaire 1” and pressed the black button, the audio informed them that they would go through another training phase. This time, the RC training stimulus was played ten times over the span of ten minutes at a fixed intensity approximately 1.2dB less than the one that woke them up.

Phase 2: Slow increments to Phase 1 AAT volume levels

Following the training phase participants were asked to go back to sleep. They were informed that this time they might wake up from the RC stimulus or from an audio alarm (a calming guitar song). Just like in Phase 1, they were told to do a RC and to press they black buttons at any point they were awoken and that by doing so, they would be informed whether they had awoken from the stimulus or whether they woke up naturally. If the awakening reason was deemed to be the stimulus (RC stimulus or alarm) they were told to complete Questionnaire 2 on the iPad. Participants then went back to sleep and the first received the RC stimulus again during REM sleep, first at approximately 1.2dBA below their AAT and in each subsequent REM epoch, the volume of the RC stimulus was increased by +0.3dBA until it reached their AAT level. After the volume of the stimulus reach Phase 1 AAT level, on the next detected REM epoch participants received the auditory stimulus again one more time at Phase 1 AAT level and after 30 seconds they received the audio alarm. Once participants were awoken from the stimulus/alarm and they pressed the button to confirm this, they were then asked to complete questionnaire 2 from the iPad. The experimenter then came in the room and removed ZMax, terminating the study.

5.2.5 EEG data preparation and analysis

5.2.5.1 Pre-processing

For pre-processing the data, EEGLAB was used (https://sccn.ucsd.edu/eeglab/index.php). A bandpass filter of 0.5 – 45 Hz was applied to the sleep EEG. As mentioned in the introduction, for developing AAT markers, it is necessary to be able to predict AATs before presenting any

stimuli, thus, only the first three hours of each recording was analysed. Three hours cut-off point was chosen to coincide with the minimum time required by ZMax's online REM algorithm to begin online REM detection.

5.2.5.2 EEG feature extraction

Using YASA, the following EEG metrics were extracted from the signal:

1) Absolute and relative band power of the signal. Frequency bands that were included in the analysis were Delta: 0.5 – 4 Hz; Theta: 4 – 8 Hz; Alpha: 8 – 12 Hz; Beta: 12 – 30 Hz; Gamma: 30 – 45 Hz

2) Nonlinear analysis metrics included fractal dimension analyses such as Irregular Resampling Auto-Spectral Analysis (IRASA; Wen & Liu, 2016), Detrended Fluctuation Analysis (DFA), Lempel-Ziv complexity, Petrosian, Katz and Higuchi. Nonlinear analysis of entropy included permutation, spectral, approximate, sample and Singular Value Decomposition (SVD).

3) One of the features of YASA (YET ANOTHER SPINDLE ALGORITHM), a Python sleep EEG analysis package, is the ability to detect sleep spindles and analyse their morphology/characteristics within a given recording. YASA outputs the following spindle characteristics:
    a. Number of spindles detected
    b. Duration of detected spindle
    c. Spindle density (detected spindles per minute)

d. Amplitude of detected spindle.
e. Root Mean Square of detected spindle.
f. Median absolute power of detected spindle.
g. Median relative power of detected spindle.
h. Median Frequency of detected spindle.
i. Number of positive peaks in a spindle.
j. Symmetry/ location of most prominent peak of detected spindle, normalised from 0 (start) to 1 (end). In spindles the symmetry should ideally be close to 0.5 indicating that the most prominent peak is halfway through the spindle.

4) YASA spindle detection algorithm was modified in order to also detect and output the morphology/characteristics of each detected frequency band bursts: Delta, Theta, Alpha, Beta and Gamma. The band characteristics for each detected wave were averaged per recording.

5) Another feature of YASA is analysis of slow-wave activity (SWA). YASA outputs the following SWA characteristics
   a. Location of the negative peak (in seconds)
   b. Location of the negative-to-positive zero-crossing (in seconds)
   c. Location of the positive peak (in seconds)
   d. Duration (in seconds)
   e. Amplitude of the negative peak (in uV)
   f. Amplitude of the positive peak (in uV)
   g. Peak-to-peak amplitude (location of the positive peak – location of the negative peak)

h. Slope of slow wave (SW: in uV/sec)

i. Frequency of the SW (in Hz)

j. Phase amplitude coupling measures between SW and spindles

   i. Phase at max sigma amplitude within a 4-sec epoch centered the negative peak of the slow-wave.

   ii. Normalized direct phase amplitude coupling (nPAC) within a 4-sec epoch centered the negative peak of the slow-wave.

6) YASA also outputs eye-movement characteristics of REM sleep. While no electrooculogram (EOG) was used, the AF7/8 electrodes of ZMax are located very close to the eyes making it possible to extract eye movements characteristics. Consequently, the following REM characteristics where extracted from each detected REM:

   a. Duration (in seconds)

   b. Density (REMs/minute)

   c. Left and right eye absolute amplitude at REM peak (in uV)

   d. Left/right eye absolute rise slope (in uV/s)

   e. Left/right eye absolute fall slope (in uV/s)

7) Finally, YASA outputs the following sleep macrostructure statistics from the hypnogram

   a. Time in Bed (TIB): total duration of the hypnogram.

   b. Sleep Period Time (SPT): duration from first to last period of sleep.

   c. Wake After Sleep Onse*t (*WASO): duration of wake periods within SPT.

   d. Total Sleep Time (TST): SPT - WASO.

e. Sleep Efficiency (SE): TST / TIB * 100 (%).

f. Sleep Maintenance Efficiency (SME): TST / SPT * 100 (%).

g. Wake, NREM1, NREM2, NREM3 and REM duration (in minutes),percentages (expressed in percentages of TST) and latencies (latencies of sleep stages from the beginning of the record)

h. Sleep Onset Latency (SOL): Latency to first epoch of detected sleep.

5.3 Results

Overall, twenty participants were including in the analysis and twelve where discarded due to the 3 following reasons: unable to sleep, major electrode artefacts and not being able to find AAT which was mostly caused by the two aforementioned reasons. Participants were split into low (below 43.8dB) and high AAT groups (43.8dB and above) based on a median split of AATs (see graph x for distribution of AAT dB scores).

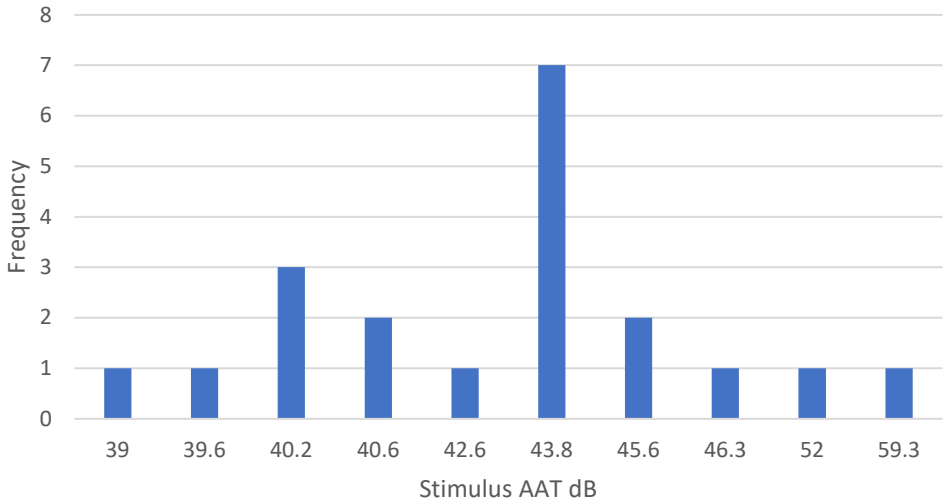

Figure 5.1 The graph displays the frequency of the stimulus decibel (dB) values that reached the auditory awakening threshold (AAT) for each participant.

In total, eleven out of twenty participants reported lucid dreaming. Five out of eleven participants who lucid dreamed performed the predetermined eye-signal (example picture here)

Seven out of ten participants experienced lucid dreams in the 1st phase of the study and four in the 2nd phase. Out of the 20 participants with good data, eight went through the second phase. This was due to high AATs and/or Hypnodyne Zmax's online REM detection algorithm not detecting enough REM epochs to reach AAT quickly enough to leave space to conduct second phase. Hypnodyne's Zmax online REM detection algorithm was accurate at detecting phasic REM (i.e., REM epochs with eye movements) but very rarely detected tonic REM epochs. Four out of the eight participants who went through the second phase of the study subsequently experienced lucid dreams.

Overall, six participants from the High AAT group and five from the Low AAT group became lucid. In total, nine participants reported performing the reality check in their dreams. The overwhelming majority of the participants who performed the reality check belonged in the High AAT group as only one participant in the Low AAT group had performed the reality check. Out of the nine participants who did the reality check, six experienced a lucid dream. On average, the duration of the lucid dream experience was 3.6 minutes. There were no significant differences between the two AAT groups in the time participants were lucid for ($p > .05$).

5.3.1 Statistical test choices

Independent-samples t-tests and Mann-Whitney U tests were run to determine if there were differences in behavioural, temperature, heart-rate and sleep EEG metrics between the high (N = 12) and low (N=8) SAT groups. Shapiro-Wilk's test of normality was used to ascertain which EEG metrics were analysed using the non-parametric Mann-Whitney U test and which EEG metrics were analysed by an independent-samples t-test. EEG metrics which had normally distributed values, as assessed by Shapiro-Wilk's test ($p > .05$) were analysed using

independent-samples t-test and conversely when Shapiro-Wilk's test was violated ($p < .05$) Mann-Whitney U test was used. When Mann-Whitney U test is appropriate the exact sampling distribution for U was used (exact p-value) instead of asymptotic-derived p-value as the sample size in each SAT group is less than 20 (Dineen & Blakesley, 1973). When Mann-Whitney U test was appropriate, the distribution of the metric scores between low and high AAT groups was then visually inspected. When the distribution shape of scores between the two groups was dissimilar this was explicitly stated and the mean ranks of each group were reported (Hart, 2001). When the distribution shape of scores was similar the median value for each group are reported. When the independent samples t-test was appropriate, Levene's test for equality of variances outcome was reported only when the assumption of homogeneity of variances was violated.

When particular variables of interested are thought to affect/drive differences between the two AAT groups (i.e., covariates), Pearson's correlations for normally distributed variables are used and Spearman's rank correlations are used for non-normally distributed data. To further investigate the driving force of potential covariates on the two different AAT groups, analysis of covariance (ANCOVA) tests for normally distributed variables were ran or Quade's tests (also known as RANCOVA, short for Ranked Analysis of Covariance) were ran for non-normally distributed dependent variables (Quade, 1979; Conover, 1998). In order determine whether ANCOVA would be an appropriate test to run the following assumptions had to be met. Firstly, there would have to be a linear relationship between the DV and the covariate for both low and high AAT groups, as assessed by visual inspection of a scatterplot. Secondly, there would have to be homogeneity of regression slopes determined by having a non-significant interaction term between the DV and the covariate ($p > .05$). Thirdly, standardized residuals of the low and high AAT group would have to be normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$). Fourth, there would have to be homoscedasticity and

homogeneity of variances, as assessed by visual inspection of a scatterplot and Levene's test of homogeneity of variance ($p > .05$). Finally, there would have to be no outliers in the data, as assessed by no cases with standardized residuals greater than ±3 standard deviations. When reporting ANCOVAS, unless stated, these assumptions are not violated.

5.3.2 Wakefulness

5.3.2.1 Behavioural measures

A Mann-Whitney U test was run to determine if there were differences in the level of tiredness felt upon waking up from the stimulus in REM between High and Low AAT groups. Participants woke up feeling more tired in the low *(Mean Rank* = 14) than in the high AAT group *(Mean Rank* = 8.17), U =76, Z = 2.276, p = .031.

A Mann-Whitney U test was run to determine if there were differences in how long (approximately) it had taken participants to fall asleep in the past month between High and Low AAT groups. Participants in the high AAT group reported that in the past month it took less time for them to fall asleep *(Mean Rank* = 7.64) than in the low AAT group *(Mean Rank* = 13.25), U = 70, Z = 2.283, p = .022.

An independent-samples t-test was run to determine if there were differences in the hours that participants reported having slept the night before the sleep study between the high and the low AAT group. Participants in the low AAT group (M = 6.188, SD = 1) reported having slept less hours the night before the sleep study, than in the high AAT group (M = 8.58, SD = 1.43), a

statistically significant difference, *M* = -2.39 , 95% CI [-3.62,-1.17], *t* (18) = -4.108, *p* = .001. Participants in the low AAT group (M = 16.50, SD = .89) were awake for more time than the high AAT group (M = 15 , SD = 1.69), measured from the time they reported awakening the day of the sleep study until the time they were scored as asleep at the sleep study, M = 1.5, 95% CI [.28, 2.7], t (18) = 2.591, p = .019, equal variances not assumed. Indeed, there was a significant negative correlation between the auditory stimulus decibel level required to reach AATs (AAT dB) for past awakening duration rho (20) = -.457, p = .043 but there was no significant correlation between AAT dB and past night sleep duration, r (20) = .297, p = .204.

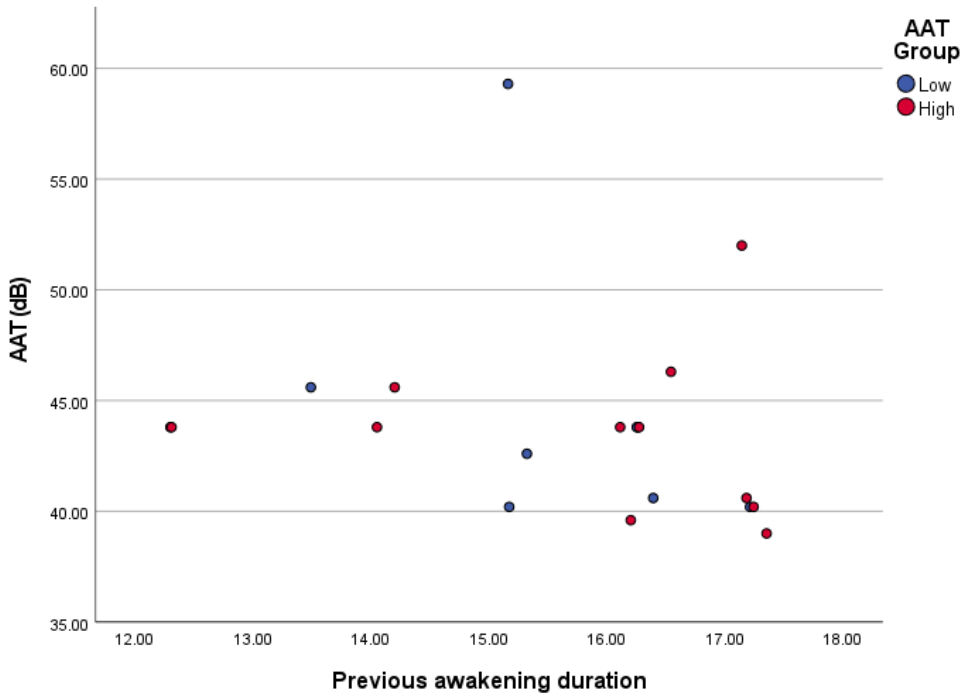

Figure 5.2. The graph displays how auditory awakening thresholds measured in decibel varied as a function of previous awakening duration between Low/High AAT groups.

Regarding PSQI questionnaire differences between the two AAT groups, participants from the low AAT group (M = 2.38, SD = 1.43) most often reported that in the past month it took them on average 16-30 minutes to fall asleep whereas most participants in the high AAT group (M = 1.55, SD = .820) reported that it took them 15 minutes or less to fall asleep, M = .830, 95% CI [.132, 1.48], t (18) = 2.510, p = .022.

Due to the significant differences in previous night sleep duration between the two AAT groups, this factor was evaluated as to whether it was having an explanatory effect on any of the significant sleep macro and macrostructure differences between low and high AAT groups. Consequently, whenever the previous night sleep duration had a statistically significant correlation between any of the reported significant macro/microstructure AAT group differences, this is reported.

There were no statistically significant differences between the two groups in age, gender, DRF, LDF, LUSK, PRMQ, ADHD, PHQ9 and GAD7 scores, subjective reports of considering oneself a light, normal or heavy sleeper, or from any other remaining PSQI questions (e.g., reports of approximate overall sleep time, sleep quality experienced in the past month), collected from the screening questionnaire $p > .05$. There we also no other statistically significant differences from subjective reports collected from the lab sleep questionnaires (e.g., in-lab dream recall measures).

5.3.2 Sleep macrostructure

There were no sleep macrostructure differences (i.e., NREM1/3, REM stage percentage differences, and NREM1/2/3/REM duration, latency, SE, SME, SOL, SPT and WASO) between low and high AAT groups, after controlling for SOL, TST and TIB, $p > .05$.

5.3.2.1 Natural awakenings & micro-arousals

A Mann-Whitney U test was run to determine if there were differences in the number of natural awakenings that participants reported during the sleep study between high and low AAT groups. Participants in the low AAT group *(Mdn* = .88) reported waking up naturally less times

than in the high AAT group *(Mdn*=2.83), *U* =13.500, *Z* = -2.711, *p* = .005. However, the number of natural awakenings were also recorded by the device each time participants woke up and pressed one of the black buttons to confirm whether they were awoken naturally or from the stimulus. The device recorded awakening times were not significantly different between the two AAT groups, > p.05.

The number of behavioural microarousals (body movements) for each sleep stage were measured through visual inspection of the accelerometer data. In addition, microarousal (MA) density for each stage was calculated by dividing number of microarousals with the respective duration of each sleep stage.

Time in bed (TIB) was found to be highly positively correlated with REM MA density, rho (20) = .707, p < .001. Thus, a RANCOVA was ran to determine whether REM MA density differences between low and high AAT group remained after controlling for TIB. After adjustment for TIB, the statistically significant differences in REM MA density between the two AAT groups remained, F(1, 18) = 5.133, p = .036, partial η2 = .222. Post hoc analysis was performed with a Sidak adjustment. Low AAT group REM MA density was significantly greater than the high AAT group (mean difference of 5.024 [95% CI, .365 to 9.683], p = .036). This suggests that while TIB influenced REM MA density, it was not the driving factor for the REM MA density AAT group differences.

5.3.3 Sleep microstructure

A summary table of significant EEG results is provided below. A more detailed description of the EEG results is found after the table below.

Table 5.1 The table shows statistically significant EEG AAT group differences from the three hour EEG recording, specifying which sleep stage they were found (Sleep Stage), which EEG metric was significant (EEG metric), on which electrode (AF7/AF8) significant differences where found and what was the difference found between the two AAT groups (Low vs High)

Sleep Stage	**EEG metric**	**Electrode**		**AAT group differences**		**Statistics**
		AF7	AF8	Low	High	
N1	Delta absolute power	✓	✓	↓	↑	AF7: $t(18) = -3.222$, $p = .005$ AF8: $U = 14$, $Z = -2.623$, $p = 007$
	Alpha relative power	×	✓	↑	↓	$t(18) = 2.373$, $p = .029$.
	Beta absolute power	×	✓	↓	↑	$U = 22$, $Z = -2.006$, $p = .047$.
	Beta burst density	✓	×	↓	↑	$t(18) = -2.209$, $p = .040$
	Beta band burst symmetry	✓	×	←	→	$t(18) = -3.757$, $p = .001$
	Gamma burst density	×	✓	↓	↑	$t(18) = -2.982$, $p = .009$
	Global Field Power	✓	✓	↓	↑	AF7: $t(18) = -2.927$ $p = .009$ *AF8:* $U = 17$, $Z = -2.392$, $p = .016$
N3	Delta burst density	×	✓	↑	↓	$U = 19$, $Z = -2.237$, $p = .025$
	ndPAC	×	✓	↑	↓	$t(18) = 2.702$, $p = .038$
	Theta burst frequency	✓	✓	↑	↓	AF7: $t(18) = 2.309$, $p = .033$ AF8: $t(18) = 2.243$, $p = .038$
	Gamma relative power	✓	✓	↑	↓	$t(18) = 2.758$, $p = .013$
REM	Theta absolute power	✓	×	↓	↑	$U = 21$, $Z = -2.083$, $p = .039$
	Beta absolute power	×	✓	↓	↑	$t(18) = -2.264$, $p = .036$
	Gamma burst oscillations	✓	×	↑	↓	$U = 20$, $Z = -2.180$, $p = .031$
	REMs density	N/A	N/A	↓	↑	$t(18) = -2.199$, $p = .045$

5.3.3.1 NREM1

Delta band power frequency characteristics

Overall, in NREM 1, participants in the low AAT group ($M = 20.62$, $SD = 6.77$) had lower absolute delta power at AF7 than the high AAT group ($M = 32.31$, $SD = 8.61$), $M = -11.69$, 95%, CI[-19.31,-4.06.83], $t(18) = -3.222$, $p = .005$. The same difference in absolute NREM 1 delta was also observed in the AF8 location for the low AAT group (Mdn =20.92) vs the high AAT group (Mdn =34.36), U =14, Z = -2.623, p =007.

Past night sleep duration was statistically significantly correlated with absolute power of NREM 1 delta at both AF7 and AF8 locations. At AF7, there was a statistically significant, large positive correlation between absolute NREM 1 delta and past night sleep duration, *r* (20) = .640, *p* = .002, with past night sleep duration explaining 32% of the variation in absolute NREM 1 delta power. At the AF8 location, past night sleep duration was significantly positively correlated with overall absolute delta was significantly positively correlated with past night sleep duration, *rho* (20) = 660, *p* = .002, explaining 33% of the variance in absolute power of delta.

Duration of past wakefulness was significantly negatively correlated with absolute NREM1 delta at AF8 *rho* (20) = -.444, *p* = .050. Based on the significant correlations between past night sleep duration and duration of past wakefulness on delta, the appropriate ANCOVA or RANCOVA tests were ran controlling for past night sleep duration and duration of past wakefulness as appropriate.

An ANCOVA was run to determine whether delta band differences at AF7 between low and high AAT group remained after controlling for past night sleep duration. After adjustment for past night sleep duration, there were no significant differences in delta at AF7 between the two AAT groups, F(1, 17) = 1.550, p = .230, partial η2 = .084, F(1,17) = 1.020, p = 327 and F(1,17) = 2.291, p = .149, respectively (see also table 5.1).

Table 5.2. The table showcases the mean (M), standard deviation (SD) and standard error (SE) differences in NREM 1 Delta μV^2 between low/high AAT groups, pre and post adjusting for past night sleep duration.

AF7 electrode		**Unadjusted**	**Adjusted**

	AAT group	***N***	***M***	***SD***	***M***	***SE***
NREM 1 Delta μV^2	Low	8	20.62	6.77	24.05	3.34
	High	12	32.31	8.61	30.02	2.56

A RANCOVA was ran to determine whether absolute delta band differences at AF8 between low and high AAT group remained after controlling for past night sleep duration. After adjustment for past night sleep duration, there were no significant differences in delta at AF7 between the two AAT groups, $F(1, 18) = .310$, $p = .584$, partial $\eta 2 = .017$. In addition, RANCOVA was ran to determine whether absolute delta differences at AF8 between low and high AAT group remained after controlling for previous awakening duration. After adjustment for previous awakening duration, there was no significant difference in delta at AF8 between the two AAT groups, $F(1, 18) = 3.797$, $p = .067$.

These results indicate that when controlling for either past night sleep duration or duration of past wakefulness through ANCOVA tests or RANCOVA, NREM 1 delta AAT group differences largely disappear in both AF7 and AF8 locations, $p>.05$. This finding is suggestive that these two covariate factors are driving in a significant way the NREM 1 delta AAT group differences.

<u>Alpha band power frequency characteristics</u>

In the alpha band, there were overall alpha between the low and high AAT group. The low AAT group had higher alpha relative power (*M* = .067, *SD* = .024) than the high AAT group (*M* = .045, *SD* = .017), at AF8, *M* = .22, 95 CI [.003, .041],t(18) = 2.373, *p* = .029.

Beta band power frequency characteristics

In NREM1, there was a significant difference in the beta band at the AF8 location between the two AAT groups. The low AAT group (*Mdn* = 1.78) had lower absolute beta power than the high AAT group (*Mdn* = 2.41), *U* =22, *Z* = -2.006, *p* =.047.

A significant difference was also found in beta band burst density and symmetry in the AF7 location between the two AAT groups. The beta density was lower in the low AAT group (*M* = 9.10, *SD* = 2.5) when compared to the high AAT group (*M* = 12.13, *SD* = 3.29), *M* = -3.03, 95% CI [-5.92, -.15], t(18) = -2.209, *p* = .040. In terms of symmetry, the Beta frequency bursts' most prominent wave (symmetry) came earlier in the low AAT group (*M* = .49, *SD* = .04) when compared with the high AAT group (*M* = .53, *SD* = .05), *M* = -.05, 95% CI [-.09, -.02], *t (*18) = -3.757, *p* = .001. NREM 1 beta symmetry at AF7 was significantly correlated with past night sleep duration, r (20) = .455, p = .044. Therefore, ANCOVA was ran to determine whether NREM 1 beta symmetry at AF7 between low and high AAT group remained after controlling for past night sleep duration. After adjustment for past night sleep duration, there was still a significant differences in NREM 1 beta symmetry at AF7 between the two AAT groups, F(1, 17) = 7.061, p = .017, partial η2 = .293. Post hoc analysis was performed with a Sidak adjustment. The low AAT group had significantly earlier prominent wave in beta bursts and was more symmetrical (i.e., closer to 0.5) than the high AAT group (adjusted mean

difference of -.056 [95% CI, -.100 to -.011], p = .017). Therefore, controlling past-night sleep duration did not eliminate AAT group differences in NREM 1 beta burst symmetry.

Gamma band power frequency characteristics

An independent samples t-test revealed differences between the high and the low AAT group in gamma frequency burst density at AF8 in the NREM1 sleep stage. The Welch t-test was chosen due to the assumption of homogeneity of variances being violated, as assessed by Levene's test for equality of variances. The low AAT group had significantly less gamma burst density (M = .4.18, SD = 2.16) when compared to the high AAT group (M = 8.74, SD = 4.59), M = -4.56, 95% CI [-7.80, -1.33], t(18) = -2.982, p = .009.

Global Field power

The global field power during NREM1, at both AF7 and AF8 locations, differed significantly between low and high AAT groups. At the AF7 location, the low AAT group (M = 30.74, SD = 10.69) had lower global field power than the high AAT group (M = 43.71, SD = 9.02), a significant difference, M = -12.96, 95% CI [-22.27, -3.66], t(18) = -2.927 p = .009. The same was true for the AF8 location, where the low AAT group (Mdn = 33.04) had significantly lower global field power than the high AAT group (Mdn = 46.84), U = 17, Z = -2.392, p = .016. Global field power was significantly positively correlated with past-night sleep duration at AF7, r(20) = .626, p = .003 and AF8, rho(20) = .669, p =.001. Consequently, one ANCOVA (AF7) and one RANCOVA (AF8) was ran to determine whether NREM 1 global field power between low and high AAT groups remained after controlling for past night sleep duration. After adjustment for past night sleep duration, there were no significant differences in NREM 1 global field power at AF7 between the two AAT groups, F(1, 17) = .378, p = .378, partial η2

= .049 or at AF8, F = (1,18) = .048, p =.829, partial η2 = .003. Therefore, past night sleep duration seems to be driving differences NREM 1 global field power differences between the two AAT groups

5.3.3.1 NREM2

There were no significant differences between the two AAT groups in any of the EEG metrics.

5.3.3.2 NREM 3

There was a higher delta burst density for the low AAT group (*Mdn* = 8.76) when compared to the high AAT group (*Mdn* = 5.6) at the AF8 location, *U* =19, *Z* = -2.237, *p* = .025. At the AF8 location, past night sleep duration was significantly negatively correlated with NREM 3 delta burst density, *rho* (20) = -.485, *p* = .030, thus explaining 24.25% in AF7 of the variance in delta burst density. RANCOVA was ran to determine whether NREM 3 delta density AAT group differences at the AF8 location remained after controlling for past night sleep duration. After adjustment for past night sleep duration, the significant differences in delta burst density between the two AAT groups disappeared, F (1,17) = .053, p = .821, partial η2 = .003.

Participants in the low AAT group (M = .20, SD = .20) had significantly higher normalised direct phase amplitude coupling (ndPAC) between slow-wave activity (SWA) and spindles at

the AF8 location than the high AAT group (M = .18, SD = .01) , t(18) = 2.702, p = .038, equal variances not assumed.

Theta band power frequency characteristics

A statistically significant NREM 3 difference was found in theta burst frequency for both AF7 and AF8 locations: the low AAT group had significantly higher theta frequency (M = 5.12, SD = .16 and M = 5.12, SD = .18, respectively) compared to the high AAT group (M = 4.97, SD = .14 and M = 4.96, SD = .12, respectively), t (18) = 2.309, p = .033 and t (18) = 2.243, p = .038, respectively.

Gamma band power frequency characteristics

At AF7 the low AAT group (*M* = .002, *SD* = .001) had significantly higher relative power of gamma than the high AAT group (*M* = .001, *SD* = .007), *M* = .001, 95% *CI* [.0003, .0020], *t*(18) = 2.758, *p* = .013. This significant difference at the AF7 location was the same for both gamma1 and gamma2, *p* <.05.

5.3.3.3 REM

Theta band power frequency characteristics

At AF7, there were REM differences in the absolute power of theta, with the low AAT group (*Mdn* = 3.28) having less absolute power than the high AAT group (*Mdn* = 4.29), *U* = 21, *Z* = -2.083, *p* = .039.

Beta band power frequency characteristics

At AF8, the low AAT group (*M* = 1.25, *SD* = .68) had lower absolute beta power than the high AAT group (*M* = 2.01, *SD* = .76), *M* = -.76, 95% CI [-1.46, -.054], t(18) = -2.264, *p* = .036.

Gamma band power frequency characteristics

There were no significant differences in absolute and relative gamma band between the low and high AAT group in REM stage, *p* >.05. However, there was a significant difference in the number of positive peaks of gamma bursts at AF7. The low AAT group (Mdn = 13) had higher number of positive peaks than the high AAT group (Mdn = 10) *U* = 20, *Z* = -2.180, *p* = .031.

REMs

Participants in the low AAT group (M = .74, SD = .52) had lower rapid eye movements (REMs) density than the high AAT group (M = 1.79, SD = 1.54), M = -1.06 95% CI [-2.09 to -.03], t (18) = -2.199, p = .045, equal variances not assumed.

Non-linear, heart rate and temperature non-significant results

Non-linear EEG analysis, heart rate and body temperature readings in all sleep stages did not show any significant differences between the two AAT groups, $p > .05$.

5.3.6 Machine Learning results

The initial database included 318 features. All EEG, heart-rate and temperature metrics collected from the three hour sleep recordings were included in the database. The EEG features that were included are outlined in '5.2.5.2 EEG feature extraction subsection' of the Methods section. In addition, all behavioural and demographic metrics were included except for behavioural metrics collected after starting the sleep study. This included gender, age, past night sleep duration and woke duration since last sleep episode. The dependent variable was AAT group membership (High/Low). The features were reduced to 187 through the use of Predictive Power Scorer (PPS), a customised Decision Tree feature importance scorer that is not included in the list of TPOT pre-processing algorithms. PPS produces the predictive weighted F1 score of each feature on the dependent variable. Features with a 0 PPS score were removed from the database leaving 187 features to the database that was analysed by TPOT. For a list of features and their respective PPS scores (see Appendix 5.1).

Following the PPS feature elimination, the remaining dataset was analysed using the TPOT algorithm to find the most optimum ML pipeline for predicting AAT membership (TPOT's function is whose function is outlined in Chapter 1, subsection '1.6.8 Machine learning methodologies used in neuroscience'). TPOT was set to run for 500 generations of pipelines with 100 offspring in each generation. This would total half a million model configurations, which were evaluated using leave-one-out cross-validation (LOOCV), thus 3.8 million models (i.e., generations [500] * offspring [100] * (number of training samples - 1 [19])) were set to

be fit and evaluated on the training data set. LOOCV trains the whole dataset by each time running the chosen ML pipeline with the whole train sample dataset except for one sample and makes a prediction for the sample that was removed. LOOCV does this for the length of the dataset – 1 times, thus for this dataset LOOCV was performed 19 times. To reduce the number of generations needed to find an optimum ML pipeline, the TPOT algorithm was set to stop when 100 generations in a row did not improve classifier prediction accuracy. TPOT was trained with the evaluation metric of achieving maximum reduction of logarithmic loss [1](Log Loss).

Log loss is the averaged difference between ground truth and logarithm of predicted score for every observation (Murphy, 2012). Due to its logarithmic nature when the prediction accuracy improves, log loss decreases slowly (the best log loss score possible is 0) but when the classifier algorithm is confident about an incorrect classification, log loss heavily penalizes the score.
As the database was roughly imbalanced, with 12 high AAT participants and 8 low AAT participants, the balanced accuracy metric was chosen in lieu of the standard accuracy[2] metric as balanced accuracy[3] avoids inflated performance estimates on imbalanced datasets (Brodersen, Ong, Stephan & Buhmann, 2010; Kelleher, Mac Namee & D'Arcy, 2015).

TPOT was stopped at generation 45 as it reached a log loss score of 0.0025. Thus, 85550 ML pipeline models were fit and evaluated in total. Overall, TPOT ran for 2 hours and 38 minutes

[1] Mathematically log loss is defined as:
binary log 〖loss=〗 -(y_i log(p_i)+(1-y_i) log (1-p_i))
[2] Standard accuracy metric is defined mathematically as:

$$\text{Accuracy}\left(y,\ y\ \right)=\frac{1}{n_{\text{samples}}}\sum_{i=0}^{n_{\text{samples}}-1}1\left(\ y_{\ i}=y_i\right)$$

[3] The balanced accuracy metric for binary classification is defined mathematically as:

$$\text{Balanced accuracy}=\frac{1}{2}\left(\frac{True\ Positives}{True\ Positives+False\ Negatives}+\frac{True\ Negatives}{True\ Negatives+False\ Positives}\right)$$

and 24 seconds on a laptop with an Intel® Core™ i7-7700HQ quad core CPU running at 2.8 Ghz and 12GB of RAM. The log loss score of 0 equalled to a mean balanced accuracy score of 100%, SD = 0.

5.3.6.1 Optimum ML pipeline

The optimum ML pipeline that was outputted by TPOT first used a feature selection algorithm called 'SelectPercentile' which is a feature selection algorithm that removes all but a user-specified highest scoring percentage of features (based on ANOVA F-values). Resulting from the application of 'VarianceThreshold' the dataset features were reduced from 187 to 10 (Appendix 5.1). Subsequently, each feature was scaled by its maximum absolute value using 'MaxAbsScaler'. After 'MaxAbsScaler' feature scaling was applied, a decision tree classifier stacking estimator was selected. A decision tree classifier (Breiman, Friedman, Olshen & Stone, 1984) is a predictive algorithm that arrives to class membership prediction by learning through a flowchart-type set of binary rules (e.g., True or False) inferred from prior data. The AAT group membership decision tree classifier predictions were then added to the database. Following the application of the decision tree classifier stacking estimator, the database features were then binarized ('Binarizer') according to a specified threshold (Appendix 5.1). The number of database features was then reduced further using recursive feature elimination ('RFE') based on an Extra Trees Classifier classification algorithm. Extra Trees Classifier is similar to the Random Forest algorithm, except that it does not bootstrap observations and nodes are split on random splits instead of best splits (Geurts, Ernst & Wehenkel, 2006). Following the Extra Trees classifier-based RFE algorithm, the least important features were pruned in a recursive process until the desired selection of features was eventually reached

(Appendix 5.1). This resulted in a feature reduction from 10 to 5 (Appendix 5.1). A further feature elimination algorithm was then applied to the database using 'VarianceThreshold', a feature elimination algorithm that removes low-variance features based on a threshold (Table 5.3). This reduced database feature from 5 to 3 (Appendix 5.1). A further decision tree stacking estimator was then applied before Microsoft's Light Gradient Boosting Machine classifier (LightGBM classifier) was chosen as the final classifying prediction algorithm. Hence, LightGBM was the final decider algorithm which made the final AAT group prediction based on the prediction probability matrixes of the chosen 2 stacking estimator and the values of the post-feature selection database features (i.e., a total of 5 feature columns).

Table 5.3 Showcases the most optimum TPOT generated pipeline steps including which pre-processing, feature selection, and classifier algorithms were applied, what their parameter values were, and in which order they were applied.

Pipeline steps	**Pre-processing algorithms**		
step	Scikit-learn name	Hyperparameters	Selected value
2	MaxAbsScaler	*N/A*	
4	Binarizer	*threshold*	*0.45*
Feature-selection algorithms			
step	Scikit-learn name	Hyperparameters	Selected value
1	SelectPercentile	score_func percentile	*f_classif* *5*
5	RFE	estimator step	*ExtraTreesClassifier (criterion="gini", max_features=0.1, n_estimators=100)* *0.35*
6	VarianceThreshold	threshold	*0.005*
Classification algorithms			
step	Package name (e.g., Scikit-learn name)	Hyperparameters	Selected value

3	DecisionTreeClassifier (stacking estimator)	criterion max_depth min_samples_leaf min_samples_split	*"entropy"* *5* *18* *8*
7	DecisionTreeClassifier (stacking estimator)	criterion max_depth min_samples_leaf min_samples_split	*"gini"* *8* *4* *8*
8	LGBMClassifier (final decider classifier)	boosting_type colsample_bytree learning_rate min_child_samples n_estimators num_leaves subsample	*"gbdt"* *0.7* *0.1* *1* *75* *4* *0.7*

5.4 Discussion

The aim of this exploratory study was two-fold. The first aim was to enhance auditory stimuli incorporation into dream content with the purpose of inducing lucid dreaming reliably and easily. To achieve this a theoretical and technical framework for an Individualised Auditory Stimulation (IAS) technique was developed. A central component to this technique is that it firstly aims to predict AATs using Machine Learning (ML) algorithms, in order to present auditory stimuli as loud as possible and to repeat the stimuli as frequently as possible, without causing any awakenings. The current study laid the foundations for the IAS technique, opting first to investigate stimulus intensity (loudness) levels that would reach individual AATs by using a data-driven approach and analysing a targeted and novel selection of behavioural and EEG metrics extracted from three hours of EEG recording time. The three-hour recording time was chosen to coincide with Hypnodyne ZMax's online REM detection algorithm, which needed at least three hours of EEG to begin detecting REM epochs in real-time. Due to low sample size due to the impact of the COVID-19 pandemic, instead of at least a three AAT

group comparison (as was initially planned), participants were split into two AAT groups (low and high) using a median split and behavioural and EEG differences were investigated. Overall, eleven out of twenty participants reported having experienced lucid dreams.

5.4.1 Behavioural Findings

Past research that utilised sleep deprivation protocols to investigate AAT has shown that AATs are increased as a function of awake time (Frederickson & Rechtschaffen, 1978). Contrary to what was expected, the low AAT group reported that on average they slept less the night before the sleep study and that they had been awake for longer than the high AAT group. While this contrasts with previous findings, these historical positive correlations of previous awakening duration had been done using sleep deprivation protocols, where participants had been asked to stay awake for very long periods of time (Frederickson & Rechtschaffen, 1978; Rosenthal, Bishop, Helmus, Krstevska & Roth, 1996). In the present study, none of the participants was awake for such long periods as the ones tested in sleep deprivation protocol studies. Thus, the results of the current study are suggestive of a non-linear relationship between previous awakening duration and AATs, where AATs initially decrease as a function of previous awakening duration but once a certain threshold of previous awakening duration is reached this relationship may then be reversed.

5.4.2 EEG findings

EEG differences between high and low AAT groups were found in the delta, theta, beta and gamma frequency bands and global field power (GFP), concentrated in NREM 1, 3 and REM sleep stages. The frequency bands exhibiting AAT group differences in both resting-state and

sleep EEG were delta, theta and beta. In NREM 2 there were no significant band power frequency differences between low and high AAT groups. Overall, for delta band power differences were found in NREM 1 and NREM 3, whilst theta band differences were found only in NREM3 and REM sleep. Regarding higher frequencies, beta band differences were found only in REM and NREM1 while gamma differences were found in NREM 1, NREM 3 and REM sleep.

5.4.2.1 Delta

The delta band seems to be most implicated in AAT group differences in NREM sleep and hence constitutes the most reliable EEG AAT marker for NREM sleep. Specifically, the low AAT group exhibited lower absolute delta power in both hemispheres in NREM 1 and NREM 3 and significantly higher delta burst density in NREM 3 than the high AAT group. In addition, in comparison to the high AAT group, there was a higher SO-spindle ndPAC in the low AAT group.

The significant differences in delta between the two AAT groups are thought to be driven at least in part by past night sleep duration and duration of prior wakefulness. These two measures were consistently found to be correlated with delta band characteristics and were found to be covariates that when controlled for, made all the delta-band frequency characteristic AAT group differences (with the exception of SO-spindle ndPAC) disappear. As mentioned earlier, in contrast to what was hypothesised, the low AAT group on average reported sleeping less the night before the sleep study and that they had been awake for a longer period of time before sleeping at the lab. These two findings are in contrast with previous research showcasing that AATs not only increase as a function of sleep deprivation measures such as previous awakening duration but also that NREM delta power increases following prolonged waking

duration in humans (Gent et al., 2020; Dijk, Beersma & Daan, 1997; Dijk et al., 1990) and animals (Gent et al., 2020; Franken, Chollet & Tafti, 2001; Jones, Vyazovskiy, Cirelli, Tononi & Benca, 2008; Martinez-Gonzalez, Lesku & Rattenbor, 2008; Franken, Tobler & Borbely, 1991). Thus, the results of the current study are suggestive of a non-linear relationship between absolute delta power and past night sleep duration on AATs. For example, it may be possible that AATs initially decreased as a function of previous awakening duration/past night sleep duration, but once a certain threshold of previous awakening duration is reached this relationship is then reversed. As none of the participants were awake for periods such as those studied in previous sleep deprivation protocols, the findings of this study suggest that previous researchers practise of only studying extreme forms of sleep deprivation (e.g., 24 to 48 hours or more) and their effect on sleep EEG measures and AATs may have obscured the whole picture of the gradual EEG changes that occur as a function of previous awakening duration and past night sleep duration. For studies investigating the effect of sleep deprivation, it may thus be of interest when and what causes a shift in delta power in individuals.

5.4.2.2 Theta

Results indicated that the low AAT group exhibited cross-hemispheric higher frequency theta bursts in NREM 3 and left-lateralised lower absolute theta band power in REM. Frontal theta has been associated with hippocampal activity, memory and learning consolidation processes and sensory processing, including motor and autonomic processes in sleep and wake (Velluti & Pedemonte, 2005). Vinogradova (2001) postulates that the theta rhythm is responsible in selecting and registering incoming stimulus information. It is therefore possible that the increase in NREM3 theta burst frequency and the decrease in absolute theta power in REM exhibited by the low AAT group is indicative of reduced thalamic gating of external stimuli processing in sleep.

5.4.2.3 Alpha

Alpha band differences were found only in NREM 1, with low AAT group having higher relative alpha power than the high AAT group. One of the hallmark features of scoring sleep onset and the beginning of NREM 1 is that alpha activity decreases by about half or more in a 30 second epoch (Britton et al., 2016). Thus, these results suggest that low AAT group alpha band transitions may be slower than the high AAT group.

It was initially hypothesised that there would be an interaction between spindle characteristics and AATs since spindles originate from thalamocortical interactions and because the thalamus is responsible for relaying sensory information to the cortex (Peter & Jones, 1991). However, in the current study there were no associations found with any spindle characteristics (e.g., spindle density) and AATs. This is in contrast to Dang-Vu, McKinney, Buxton, Solet & Elleborgen's (2010) findings who found that higher spindle density was correlated with higher AATs. Whether this was due to differences in protocol, reduced sample size or spindle detection algorithm is unclear. Nevertheless, the hypothesis on spindles being a biomarker for vulnerability to auditory stimuli during sleep is not supported by the current study.

5.4.2.4 Beta

The low AAT group had significantly lower absolute beta in NREM 1 and REM, and an earlier high peak in beta burst activity NREM 1. From studies of disorders which exhibit high AATs, such as in Post-Traumatic-Stress Disorder (PTSD; Dagan, Lavie & Bleich, 1991; Woodward, Murburg & Bliwise, 2000) and delayed sleep-wake phase disorder (DSWPD; Solheim et al., 2018), one could draw inferences as to the differences between low and high AAT groups found in this study as being due to the decrease in beta in the low AAT group found in the

present study. For example, Woodward, Murburg & Bliwise (2000) demonstrated that PTSD participants exhibit higher REM beta than controls.

5.4.2.5 Gamma

Concerning the gamma frequency band, it was found that the low AAT group had lower gamma burst density in NREM 1, higher relative power of gamma in NREM 3 and a higher number of positive peaks in gamma bursts during REM. In regard to the higher relative power in NREM 3 this may be an indicator of shallower sleep depth exhibited by the low AAT group. This supposition is derived from the fact that gamma band activity is at its highest during wake and at its lowest during NREM 3, when compared to other sleep stages (Cantero, Atienzaab, Madsen, Stickgold, 2004). Moreover, Cantero, Atienzaab, Madsen, Stickgold (2004) postulate that gamma might be functionally involved in mediating arousal and sensory regulation with decreased gamma equating to reduced sensory processing ability. Also, given that gamma is often associated with signal noise, the increase in positive peaks of gamma bursts in REM may indicate increase in frequency and duration of gamma bursts due to an increase of movement artefacts caused by the higher number of REM MAs found in the low AAT group.

5.4.3 Focusing in on REM sleep AAT group differences

Concerning REM sleep differences between the two AAT groups, the low AAT group exhibited less absolute theta and beta power, lower eye movement density, a higher number of positive peaks in gamma frequency bursts and higher number of REM MAs than the high AAT group. The higher density of eye movements is indicative of more phasic REM sleep in the high AAT group. Since, phasic REM sleep has been associated with the highest AAT threshold

of all sleep stages it may thus explain differences between low and high AAT groups (Ermis, Krakow & Voss, 2010). In addition, an increase in phasic REM in the high AAT group could explain why there were also less REM MAs in the high AAT group, as tonic REM is characterised by an increase in muscle twitches (Simor, van Der Wikj, Gombos & Kovacs, 2019). Contrastingly, the presence of ponto-geniculo-occipital (PGO) waves (Callaway et al., 1987; Datta and Hobson, 1994; Lim et al., 2007), one of the features of phasic REM, is likely to have provided a greater inhibition of cortical processing of external stimuli in the high AAT group (Lim et al., 2007; Miyauchi et al., 2009; Wehrle et al., 2007). While the low AAT group reported more overall awakenings than the high AAT group, this was not corroborated by the times participants had pressed the buttons on the device to receive auditory confirmation as to whether they were awoken naturally or from the stimulus. As there were no differences in WASO between the two AAT groups, these results suggest that the low AAT group either experienced more false awakenings or that they had woken up with significantly more sleep inertia than the high AAT group and were unable to press the device buttons before falling asleep again. The latter possible explanation would also explain why WASO did not differ significantly between participants as each full awakening might have been very brief with no significant change in brain activity or muscle movement. A clear answer would have been provided if ZMax included an EMG sensor since an increase in EMG GFP would clearly indicate whether participants were awake. Nevertheless, conclusions may be drawn from the literature where it has been found that poor sleepers, such as insomniacs, have a sleep-wake perceptual deficit (Mercer, Bootzin & Lack, 2002). It has been suggested that sleep-wake misattribution in insomniacs is thought to occur due to higher cortical activation during sleep, thus making it more difficult for them to discriminate between sleep and wakefulness (Mercer, Bootzin & Lack, 2002). While the participants in the present study did not have an indication of insomnia (as assessed by the PSQI) the low AAT group did report sleeping less the night

before the sleep study and reported that in the past month it had taken them on average longer to fall asleep (15-30 minutes on average) than the high AAT group (0-15 minutes on average). As such, it is likely that sleep-wake misattributions increase as a function of previous night sleep duration and sleep onset duration.

The study utilised machine learning to predict AATs, splitting participants, using a median split, into a high and a low AAT group. PPScore, a decision-tree based ML algorithm was used to reduce the number of features required to predict AAT group membership and subsequently TPOT was used, a genetic algorithm which searches for the best combination of pre-processing, feature selection and ML classifier(s) pipelines to make predictions. TPOT was able to produce an ML pipeline that was able to predict AAT membership with 100% accuracy. We hope that future studies will utilise this ML pipeline to predict and adjust stimulus intensity accordingly prior to stimulating participants in order investigate other aspects of the IAT technique such as adjusting the rate of stimulus presentation to the individual.

5.4.4 Study limitations and future direction/improvements to the IAS protocol

5.4.4.1 EEG acquisition and analyses

One of the main aims of the thesis was to investigate lucid dream induction techniques using small wearable technology. This led to some limitations such as only being able to analyse frontal EEG in two electrode locations (AF7/8) that are not the usual AASM frontal EEG derivations (F3/F4). A full PSG study with EEG electrodes placed over the frontal (F3/4), somatosensory (C3/C4) and temporal (T3/T4) and occipital cortex (O1/2), could lead to stronger predictors of AATs.

In addition, EEG network connectivity measures between the different brain areas (facilitated by the use of more electrodes) could provide better markers for predicting sensory processing in sleep. For example, it is likely that slower connectivity should lead to higher AATs. Sleep deprivation studies showcase that sleep deprivation leads to a loss of functional connectivity in frontal brain regions (Verweij et al., 2014). To date there have been no EEG network connectivity studies done on AATs.

Furthermore, by analysing additional brain areas it is likely that stronger predictors of AATs could be found. For example, investigating brain activity in the motor (measured at C3/4), auditory, (measured at T3/4) and prefrontal cortices (best measured at F3/4) may yield stronger predictors of AATs. These areas are involved in different ways in sensory processing and are found to be activated upon presentation of external stimuli during sleep despite the thalamic sensory gating that occurs during sleep (e.g., Portas, et al., 2000; Issa & Wang, 2008; Kouider, Andrillon, Barbosa, Goupil & Bekinschtein, 2014; Vallat et al., 2017; Ruby et al., 2013; Perrin, Garcia-Larrea, Mauguiere & Bastuki, 1999; Eichenlaub, Bertrand, Morlet & Ruby, 2014). For example, as mentioned in Chapter 2 and the introduction of this chapter, the sleeping brain is activated differently when presented with one's own name, showing increased activation in the frontotemporal regions of the brain (Vallat et al., 2017; Ruby et al., 2013; Perrin, Garcia-Larrea, Mauguiere & Bastuki, 1999; Eichenlaub, Bertrand, Morlet & Ruby, 2014). In addition, the motor cortex seems to be activated during sleep upon presentation of motor response stimuli that participants were trained to respond to during wake (Kouider, Andrillon, Barbosa, Goupil & Bekinschtein, 2014). Finally, ponto-geniculo-occipital (PGO) activity, which originates from the thalamus, is best measured at the occipital area (O1/2) and the addition of occipital electrodes could thus provide insights as to the level of thalamic gating of external stimuli (Waterman, Elton, Hofman, Woestenburg & Kok, 1993; Ermis, Krakow & Voss, 2010).

5.4.4.2 Additional EEG analyses

In terms of specific, additional EEG analyses, the ML algorithm of the IAS protocol could potentially benefit from event-related synchronisation/desynchronization (ERS/ERD) and auditory event-related potential (AERP) analysis of the brain response to the stimulus during the training phase. A subsequent analysis/comparison could be made of ERS/ERD and AERP following presentation of the stimulus during REM sleep at safe auditory awakening sub-threshold. The use of ERS/ERD and AERP analysis for predicting AATs should also be explored not just for offline processing but also online. Since it is recommended that stimuli are presented at least forty-five times in order to conduct ERP analysis of lateralised readiness potential (LRP; Boudewyn, Luck, Farrens & Kappenman, 2018), such an increase in the number of stimulus presentations during the training phase should be welcomed as it is likely to increase the conditioning of performing a reality check following the presentation of the stimulus in REM sleep.

5.4.4.3 EEG recording phenotype duration

In the current study, the three-hour AAT phenotype EEG recordings started from the moment that the experiment started. Firstly, this included 1.5 minutes of resting state, a short-pre-recorded audio briefing of the study and the 10-minute training session which had a fixed duration for all participants. Secondly, it also included the time that participants took to fall asleep which varied per participant, from as little as around sixteen minutes to almost fifty-two minutes. Thus, the amount of sleep EEG data varied per participant. In the future, it would be best to start recording countdown from the first instance of sleep (e.g., NREM 1) as this would ensure higher uniformity of the sleep EEG data between participants and is likely to increase predictive accuracy of AATs.

5.4.4.4 Inclusion of an audiometer device

Human hearing levels vary per individual; for example, they vary by age (Profant et al., 2019) or by hearing damage (Daniel, 2007). As the IAS technique relies on presenting auditory stimuli close to awakening thresholds, the inclusion of an audiometer device to measure interindividual hearing levels is likely to benefit the technique. If the inclusion of audiometry is found to be beneficial then the technology used in clinical settings or labs to measure hearing loss/perception, could also be included in future and upcoming lucid dream induction devices (Mota-Rolim, Pavlou, Nascimento, Fontenele-Araujo & Ribeiro, 2019). In recent years, just as PSG technologies have made it to the mainstream market in the form of fitness trackers (which score sleep through HRV measured at the wrist) and EEG sleep wearable devices such as Dreem (https://www.dreem.com) and Philips SmartSleep Deep Sleep Headband (https://www.usa.philips.com/c-e/smartsleep/deep-sleep-headband.html) are an expanding market, so is audiometer technology becoming more widely available. For example, the Nura headphones (https://www.nuraphone.com/) calibrate sound to the individual using ultrasensitive in-ear microphones which measure otoacoustic emissions (OAEs) produced in response to a variety of tones played during a calibration phase. OAEs are extremely low sounds emitted by the cochlea which are produced in response to auditory stimuli and are used in clinical settings to measure hearing loss (Stach, 2003). Thus, Nura showcases that such technology could easily be added in small sleep wearables that are used for lucid dream induction.

5.4.4.5 Analysis of phasic vs tonic REM

In the future, subdividing REM into phasic and tonic REM and extracting EEG features of each, may yield greater predictive AAT biomarkers. As mentioned earlier in this discussion

section, Ermis, Krakow & Voss (2010) had found elevated delta in high AAT participants in NREM 3 and in phasic REM. They also found that the AATs from tonic REM were similar to that of NREM 2, showcasing that NREM 3 and phasic REM are the sleep stages with the highest inhibition of external stimulation. Their bandpower analysis revealed that overall there was higher gamma and alpha power and lower beta power in phasic compared to tonic REM sleep. Based on the results of Ermis, Krakow & Voss (2010), it is also suggested that future studies utilising the IAS technique keep different stimulus intensity increment counters for phasic and tonic REM. This is because in Ermis, Krakow & Voss (2010), tonic REM has been found to have a much lower AAT than in phasic REM, more closer to NREM 2 and as such the level of intensity of a stimulus presented in phasic REM may lead to an awakening in tonic REM.

5.4.4.6 Analysis of EMG activity

The inclusion of a full PSG study would also allow for the use of EMG sensors, which are typically applied to the chin and legs to measure level of muscle atonia and behavioural MAs (in the form muscle twitches/movement). In the present study, the use of an accelerometer did not allow for the measuring of muscle atonia and therefore the ability to measure the amount of behavioural MAs accurately was somewhat hindered. The accelerometer sensor is located in the ZMax box that is placed on the forehead. As a result, limp movements/twitches would not be detected unless they caused a head movement. Thus, the addition of EMG sensors would not only allow for more accurate scoring of behavioural MAs, but also EMG global field power could serve as a novel biomarker for predicting AATs. While REM atonia indexes (transformed EMG global field power values during REM sleep) have been investigated for disorders such as Parkinson's (e.g., Ferri, Fulda, Cosentino, Pizza & Plazzi, 2012) and REM behaviour

disorder (RBD; e.g., Frauscher et al., 2012) and RBD with and without Obstructive Sleep Apnoea (OSA; McCarter et al., 2014), they have not been investigated in AATs. REM atonia index for both tonic and phasic REM could serve as a valuable EMG marker for AATs.

5.4.4.7 Sample size

As with most psychophysiological studies, a higher sample size could increase reliability. In this instance by improving accuracy of predicting AATs for the IAS technique by providing the ability to accurately predict exact AAT dB value through ML regression prediction (instead of ML classification) or would at the very least allow for a ML classification with a higher number of AAT groups (e.g., splitting of AAT groups into 3 or more categories, i.e., low, medium, high). A higher sample size is also likely to reduce the likelihood of the ML pipeline overfitting on the training data rather than finding a general predictive rule for a wider set of participants (Dietterich, 1995). As mentioned above, this was not possible in the current study due to the Covid-19 pandemic.

5.4.4.8 Choice and number of reality checks

In the current study not all reality checks were successful. Indeed, three out of nine participants who performed the reality check whilst dreaming did not experience nasal air flow despite dreaming about blocking the nasal air passage whilst trying to breathe through it. Thus, in future studies, the inclusion of performing more than one reality check is advised. Various reality checks have been proposed in the literature (Stumbrys et al., 2012) that could be

employed in addition to pinching of the nose, such as trying to pass the fingers of one hand through the palm of the other hand hand whilst looking at your hands (they tend to appear deformed in dreams).

5.4.4.9 Inclusion of a one-week sleep diary prior to the sleep study

An important factor that may impact AATs which was not included in the present study was that participants were not instructed to keep a consistent sleep schedule, one week prior to the sleep study and/or they were not asked to keep a one-week sleep diary. Deviation from average week sleep duration the night before the study, as well as deviation from the weekly average awakening duration the day of the sleep study may further drive sleep pressure and sleep depth thus impacting the level of AATs.

5.4.4.10 Predicting rate of presentation in addition to stimulus intensity

In the present study, stimuli were presented during REM sleep once every thirty seconds of REM, specifically mostly during phasic REM. Due to limitations of ZMax's online REM detection algorithm, participants received the stimulus mostly in phasic REM. Thus, oftentimes, the interstimulus interval was higher than every 30 seconds of REM. As mentioned in the introduction, in addition to predicting the intensity of the stimulus required to reach ATs, the goal of the IAS technique is to also predict the stimulus presentation rate. Depending on the individual, the stimulus could be presented more often than once every thirty seconds of REM. The supposition made here is that the louder and the more frequent the stimulus is presented without causing awakenings, the likelihood of stimulus incorporation will be increased along with the possibility of inducing lucid dreams. The reasoning behind this is that

the closer one is brought to awakening, the more likely it will be that the thalamic sensory gates become more open, thus allowing stimuli to pass through and be incorporated into the dream content. In addition, neuroimaging studies have shown that the more the frontotemporal regions of the brain become activated, the more likely one is to experience lucid dreams (Voss, Holzmann, Tuin & Hobson, 2009; Dresler et al., 2012).

5.4.4.11 Modifying brain activity through auditory stimulation

Following successful prediction of stimulus rate and presentation and subsequent adjustment of stimulus properties to be as close to individual AATs as possible, we surmise that the next step to ramp up LD induction rates would be to entrain brain activity to resemble that of those who report external stimulus incorporation. This can be achieved through serial awakening paradigms following presentation of adjusted auditory stimuli. Subsequently, EEG differences between participants who experienced incorporated stimuli into the dream content and those who did not can be investigated. Depending on the results of such an investigation, EEG features which are found to be beneficial for successful stimulus dream incorporation could be entrained with techniques outlined in Chapter 2, such as closed/open-loop auditory stimulation (Zhang & Gruber, 2019).

5.4.4.12 Inclusion of a control group

In the present study there was no control group, hence the possibility of a placebo effect cannot be discarded. Future studies building upon the IAS technique should use control groups to control for this effect.

5.4.5 Conclusion

The current study investigated the feasibility of the IAS technique on small wearable technology and laid the foundations and direction for its further development. The technique utilised for the first time the use of self-relevant stimuli (i.e., calling one's own name and being told that one is dreaming) for the induction of lucid dreams. The study was also the first to use self-relevant auditory stimuli that were adjusted to individual AATs. The IAS technique induced lucid dreams in 55% of the participant sample, one of the highest induction rates using external stimuli, although without a control/sham stimulation group. In addition, the present study utilised ML algorithms for the first time in the history of lucid dreaming and AAT research to investigate whether AATs could be predicted. The prediction of AATs through the use of ML algorithms was highly successful showcasing a 100% prediction accuracy. However, although attempts were made to reduce the problem of overfitting through the use of feature selection algorithms and LOOCV, due to the relatively small sample size, we cannot discount that the ML algorithm overfitted to the dataset. Hence, future studies should increase sample size considerably in order to avoid this possibility.

CHAPTER 6

General discussion

The goal of this thesis was to investigate lucid dreaming frequency (LDF) correlates and to explore the efficacy of LD induction techniques, in order to work towards producing an LD induction technique that induces LDs reliably and easily. For this reason, this project revolved around 3 main areas:

- The exploration of possible cognitive and metacognitive correlates of LDF
- The investigation into the efficacy of LD induction techniques, particularly focusing on cognitive and external stimulation techniques
- The use of a dedicated LD induction wearable device and app for delivering cognitive and external stimulation LD induction techniques.

In addition, given that the association of these three topics has been studied in the past (whether it be individually or combined), this thesis sought to address methodological limitations that have been raised against each of these topics and to propose new ways forward.

6.1 Individual differences in lucid dream frequency studies

The first experimental step taken was to study LDF correlates through an online survey that was sent out to LD-related forums. The survey data collection achieved a high participant count as it collected 1015 responses from 73 countries. The survey in Chapter 3 investigated several novel LDF correlates as well as tried to replicate a few past LDF correlates. Moreover, it looked into LD induction technique practices of LD-related online communities.

Firstly, the survey investigated two cognitive LDF associations relating to dream recall ability and waking memory. Dream recall ability was assessed using two types of dream recall measures: dream recall frequency (DRF), which refers to how frequently one recalls having dreamed, and dream recall completeness (DRC), which refers to how complete one's dream recall memory is. The study found a significant association between DRF and LDF, showing that the ability to frequently recall having dreamt increases the likelihood of experiencing LDs more often, thus replicating past research findings into this relationship (e.g., Wolpin, Marston, Randolph & Clothier, 1992; Schredl & Erlacher, 2004; 2011; Hess, Schredl & Goritz, 2016). Subsequently, results from the DRC (formulated and tested for the first time in this thesis) showed that not only high LDF participants recall having dreamt more often, but they also the memory of their dream memory recall is more complete than that of low LDF participants. As discussed in chapter 2 and 3, this enhanced dream recall ability and LD ability is likely due to the shared biological differences in prefrontal and temporal brain areas that high dream recallers (Vallat, Eichenlaub & Ruby, 2018; Eichenlaub et al., 2014 and frequent/experienced lucid dreamers (Filevich, Dresler, Brick, & Kuhn, 2015; Stumbrys, Erlacher, & Schredl, 2013; (Dresler et al., 2012; Voss & Voss, 2014) have when compared to those with low dream recall ability and who are infrequent/inexperienced lucid dreamers.

After looking into the ability to recall dreams, the survey looked into waking memory ability, specifically looking at retrospective and prospective memory ability. Retro/prospective memory was measured through the Prospective and Retrospective Memory Questionnaire (PRMQ; Smith, Della Sala, Logie, & Maylor, 2000). PRMQ measures the frequency of retrospective and prospective memory mistakes, dividing these memory mistakes into short-term and long-term related mistakes, and into environmentally cued and self-cued mistakes (Smith, Della Sala, Logie, & Maylor, 2000). Initially, we hypothesised that prospective

memory ability would be more, or solely correlated with LDF when compared to retrospective memory ability. The reason behind this supposition was that certain LD techniques, such as the MILD technique, are thought to rely on prospective memory ability (Baird, Mota-Rolim & Dresler, 2020; Stumbrys et al., 2012). However, results showcased that all prospective and retrospective PRMQ factors correlated with LDF, with the highest correlated PRMQ factor being the frequency of retrospective memory mistakes that are environmentally cued. These results back the continuity hypothesis between waking and dream cognition and, whilst not specifically tested, we hypothesise that prospective memory ability is more involved when practising LD induction techniques and waking retrospective memory ability allows one to spot dream scenario incongruences to waking life. It is also likely that higher retrospective memory ability allows for higher DRF which in turn increases likelihood of recalling LDs.

The continuity hypothesis is also supported by the meta-cognitive LDF associations that were explored in the chapter. The thesis took a deeper dive into past associations of mindfulness and LDF while attempting to replicate the findings of research by Blagrove & Hartnell (2000) who found that higher LDF is associated with higher levels of Need For Cognition (NFC; Cacioppo & Petty, 1982). Specifically, we opted to use the Five Facets of Mindfulness Questionnaire (FFMQ; Baer et al., 2006), which splits mindfulness into five different factors ("Observe", "Describe", "Awareness", "Non-Judge", "Non-React"), instead of the Freiburg Mindfulness Inventory (FMI; Buchheld, Buttenmullerm, Kleinknecht & Schmidt, 2006), which was used in past LD research (Stumbrys, Erlacher & Malinowski, 2015; Stumbrys & Erlacher, 2016), that splits mindfulness into "Presence and" Acceptance "factors. Our study found a significant association between all FFMQ factors except the "Non-Judge" factor, with the highest LDF correlation being the FFMQ factor "Observe". Moreover, we found that higher levels of mindfulness are not only associated with higher LDF but also with higher LD skills, thus

replicating past findings by Stumbrys & Erlacher (2017). We investigated this relationship using the lucid dreams skills questionnaire Lucid dreaming Skills Scale (LUSK; Schredl, Rieger & Goritz, 2018), which is arguably a more in-depth LD skills questionnaire than the one used in Stumbrys & Erlacher (2017). These results suggest that mindfulness plays a role in allowing oneself to realise that one is dreaming through a transferable ability while awake to be more mindful of their present experience and through a shared biological link between lucid dreaming state and mindfulness that results in increased prefrontal brain activity and greater grey matter density (Voss et al., 2009; Dresler et al., 2012; Filevich, Dresler, Brick, & Kuhn, 2015; Stumbrys, Erlacher, & Schredl, 2013; Creswell, Way, Eisenberger, & Lieberman, 2007; Farb et al., 2007).

After investigating cognitive and metacognitive correlates of LDF, the survey enquired about dream attitudes/beliefs and found that they explain the gender differences in LDF observed in the survey. Specifically, women were found to have higher LDF and DRF than men, a finding that is in line with past research findings (Bulkeley, 2014; Hess, Schredl & Goritz, 2016; Schredl, 2002). The finding that women were found to be more engaged with their dreams during wakefulness (e.g., through dream journaling and sharing dreams with others) and to have more positive dream attitudes/beliefs, showcases the importance of increasing LDF through activities and habits that bring dream consciousness into wakeful awareness.

When looking into sleep quality measures, the higher frequency of midnight awakenings was correlated with higher LDF, a result that was interpreted as midnight awakenings acting as a form of surrogate Wake Back to Bed (WBTB) technique. Similar to the proposed mode by which the WBTB technique increases LD likelihood, we hypothesize that midnight awakenings

increase cortical activation, and thus when returning to sleep, key areas related to LD are significantly more activated, increasing LD likelihood (Smith & Blagrove, 2015).

Finally, the survey on LD induction techniques revealed that reality testing, WBTB, Wake-Induced Lucid Dreaming (WILD), and MILD are not only popular but also considered to be highly efficacious at inducing LDs and hence strengthened the choice to use the combination of the RT + WBTB + MILD techniques in the subsequent experimental chapter.

Taken together, this chapter provided 2 main outcomes: 1) The variety of waking cognitive and metacognitive LDF correlates further support the continuity hypothesis between wake and dreaming consciousness; 2) It strengthened the decision to select the DRCF, FFMQ and PRMQ questionnaires to investigate the interplay of individual differences in dream consciousness in the subsequent two-week study that investigated the efficacy of the RT + WBTB + MILD technique combination.

6.2 Investigation into the effectiveness of the Reality Check, Wake-Back-to Bed and Mnemonic Induction of Lucid Dream protocol

Continuing with the goal of the thesis to investigate how LDF correlates affect the efficacy of LD induction techniques, the next chapter investigated the combined efficacy of the Reality Testing (RT), the Wake-Back-To-Bed (WBTB) and the Mnemonic Induced Lucid Dream (MILD) techniques, and which had been found in the previous chapter to not only be the most popular, but also considered the most efficacious among the online LD community. Moreover, the study combined all three techniques following past results by Aspy et al. (2017) and Aspy

(2020), who found that combining them led to the highest LD induction rates, when compared to trying them in isolation, or when compared to other types of cognitive techniques.

The study conducted in chapter 4 is very similar to the protocol that Aspy et al. (2017) used, in that it was a two-week protocol, with the 1st week acting as the "baseline week" (no LD techniques attempted) and the 2nd week consisting of 7 days were the RT + WBTB + MILD technique was performed. Moreover, all questions used in Aspy et al (2017) were also included in the study. In addition, we increased the number of questionnaires used in the pre-test phase as well as during the two-week protocol. Furthermore, we made modifications to the way the combination technique was practised in the 2nd week. Specifically, in line with the thesis goal to investigate the interplay between individual differences and different cognitive LD induction techniques, we included a battery of the additional pre-test questionnaires used in chapter 3, including DRCF, FFMQ and the PRMQ. Moreover, during Week 1 and Week 2 we included the LuCiD questionnaire (Voss et al., 2013), which measures dream consciousness over 8 different factors: INSIGHT, CONTROL, DISSOCIATION, MEMORY, THOUGHT, REALISM, NEGATIVE and POSITIVE EMOTION. This was done to enquire how individual differences interplay with LD induction success and to ascertain whether dream consciousness shifts during Week 2, regardless of successful LD induction. In terms of MILD technique application, our study differed from Aspy et al. (2017) in the following ways:

- We only tested the RT + WBTB + MILD technique, as it was found to be the best performing in both Aspy et al. (2017) and in Aspy (2020);

- The MILD technique was delivered in an audio-guided form that was listened to while falling asleep after the WBTB method; this had never been attempted before in the

literature. This was done to further ensure that participants practised the MILD technique mentally in a consistent manner. Hence, another goal of the chapter was to evaluate whether this approach improves or hinders LD induction rates when compared to past studies;

- We added dream work practise in the form of observing dream signals, i.e., dream scenario incongruences to waking life, and categorising them appropriately using dream sign categories originally developed by Levitan (1992). Thus, dream signs were split into 4 categories: EGO (i.e., dream signs related to self), CHARACTER (i.e., dream signs related to other characters), OBJECT (i.e., dream object related to dream signs) and SETTING (i.e., dream signs related to the dream setting/place) dream signs. The dream signs work was included to not only increase participant's critical thinking about their dream(s) but also to be used as part of the dream rehearsal aspect of the MILD technique. Specifically, participants were instructed to visualise each waking incongruence (i.e., dream singing) they observed in the dream when they woke up (or the latest dream they could remember if they did not wake up remembering having dreamt) and to visualise noticing them and becoming lucid;

- Prior to performing the MILD technique, we included an audio-guided progressive muscle relaxation, to be more in line with LaBerge's suggestions, who is the creator of the MILD technique (LaBerge & Rheingold, 1990).

Research results from the first week (without using LD techniques) indicated that high DRF participants reported more Week 1 dream recall days, were able to recall more dream details and reported higher LuCiD scale factor scores, even when removing participants who

experienced LDs during the first week. These results reveal how interlinked DRF and LDF are, both biologically (as they involve similar regions; Eichenlaub et al.,2014; Dresler et al., 2012; Voss & Voss, 2014), but also phenomenologically. Surprisingly, we found no correlation between measures of the Prospective and Retrospective Mistakes Questionnaire (PRMQ) and any of the Week 1 log-book queries, including the average LD induction rate, DRA, or LuCiD scale (nor in Week 2 log-books). This is unexpected, given that the results in this chapter and chapter 3 indicate a correlation between PRMQ and higher DRF and higher LDF-related questions. Overall, these results provided longitudinal support to Chapter 3's findings of a strong association between general DRF, general DRC, and the ability to remember more dream details (DRA) in Week 1.

In Week 1, all FFMQ factors except "Acting with Awareness" were found to be associated with MEMORY and THOUGHT, POSITIVE/NEGATIVE EMOTION LuCiD factors. Thus, for the first time, our results indicate a possible mode through which mindfulness has been found to affect dream consciousness in past research (e.g., Stumbrys, Erlacher & Malinowski, 2015; Stumbrys & Erlacher, 2016) towards a greater LDF.

When it came to Week 2 results, overall, 41.07% of participants who reported remembering having dreamt at least once in Week 2, experienced lucid dreaming. The present study's overall LD induction success percentage is thus lower than the 53.2% LD induction success rate reported in Aspy et al. (2017) This is not to be interpreted as an inferior result, as Aspy's sample was not only larger but it also included only participants who completed the full two-week study, whilst we included participants who dropped out before completing the study.

Participants who experienced LDs in Week 2 scored higher on the LuCiD variables INSIGHT and THOUGHT in week 1 and had higher DRF and LDF scores overall. Thus, baseline ability to remember dreams, higher frequency of experiencing lucid dreams and higher baseline metacognitive capacity in dreams is likely to facilitate LD when using cognitive LD induction strategies. Overall, LuCiD factors INSIGHT, and DISSOCIATION increased significantly from Week 1 to Week 2.

Surprisingly, we did not find mindfulness and retro/prospective memory ability differences between people who had lucid dreams and those who did not. As a result, the long-held assumption that MILD LD success is contingent on the capacity to involve prospective memory mechanisms (e.g., Baird, Mota-Rolim & Dresler, 2020; Stumbrys et al., 2012) is challenged.

The study also replicated several results from Aspy et al. (2017), including: 1) RT + WBTB + MILD is efficacious as there was a significant increase in LDs from baseline week, regardless of prior experience with the technique and regardless of LD technique practise frequency; 2) Practising RT + WBTB + MILD increases dream recall ability, an effect that is likely attributed to increased cortical activation caused by performing the WBTB technique (Wamsley, Hirota, Tucker, Smith, & Antrobus, 2007; Smith, & Blagrove, 2015); 3) RT practise in itself is not particularly efficacious as inducing LDs, as only five LDs occurred prior to participants performing the WBTB + MILD technique in the latter part of the night. These results back previous findings which show that combining RT with other techniques is more effective (Purcell, 1988; Paulsson & Parker, 2006; Aspy et al., 2017).

In contrast to Aspy et al. (2017), we discovered that sleep onset latency (SOL) had no effect on LD induction rates and that waking up from an LD did not reduce morning tiredness. We

postulate that regarding SOL differences, the cause is likely due to the addition of asking participants to complete a pre-WBTB+MILD questionnaire and the addition of the audio-guided progressive relaxation and MILD technique tape which significantly affected SOL in itself.

Overall, the study provided a more in-depth exploration not only on how the practise of the RT + WBTB + MILD technique impacts dream consciousness but also how several LD correlates impact baseline dream consciousness. Although LD induction success and LD induction rate was lower than the one is Aspy et al. (2017), we hypothesise that had we had a larger sample that completed the full two-week protocol our LD induction rates would be more similar to Aspy et al (2017). The study paved the way for new research lines that are discussed in detail in chapter 4 and in section 6.4 below.6.3 “Achilles, you are dreaming!” Investigating the effect of receiving personalised audio that is adjusted to individual awakening thresholds: A machine learning approach

6.3 “Achilles, you are dreaming!” Investigating the effect of receiving personalised audio that is adjusted to individual awakening thresholds: A machine learning approach

The final study chapter in this thesis developed a novel external stimulation technique called the Individualised Auditory Stimulation (IAS) technique. The IAS technique proposes that in order to enhance stimulus incorporation rates and therefore LD induction rates, 1) the stimulus properties need to be adjusted to the individual; 2) the stimulus needs to be semantically rich; 3) the stimulus chosen should modulate brain activity in such a way that it resembles the brain activity observed in those experiencing LDs.

Hence, the IAS protocol suggests that the stimulus intensity and presentation rate should be adjusted to the individual, as there exists a large variation in stimulus awakening thresholds (so that it is presented as close, but safely below individual stimulus awakening thresholds (SATs)). This supposition was based on previous research that suggested that successful stimulus incorporation happens when the stimulus causes a micro-arousal (MA) and the stimulus becomes recontextualised in the dream scenario through a multisensory integration process (Solomonova & Carr; 2019). Furthermore, since it has been demonstrated that there exists a large variation in SAT from person to person (Appel, Pipa & Dresler, 2017; Solomonova & Carr, 2019), a one-size-fits-all stimulus adjustment of its properties may cause some to awaken from the stimulation or the stimulus may be too weak to be incorporated into the dream content (Appel, Pipa & Dresler, 2017). Additionally, work done in chapter 2 demonstrated that studies that attempted some form of stimulus property adjustment had more favourable results (e.g., LaBerge, Levitan, Rich, & Dement, 1988; Reis, 1989; Schädlich & Erlacher, 2014; Erlacher et al. 2020).

Therefore, the IAS technique proposes that in order to achieve successful prediction of SATs, the stimulus properties need to be adjusted prior to any stimulation based on predictive modelling from behavioural and physiological data acquired prior to any stimulation. To achieve this, the work done in chapter 5 utilised a small research-grade EEG wearable device combined with advanced machine learning (ML) algorithms to build a database of behavioural and physiological data wherein the algorithm was trained to predict auditory awakening thresholds (AATs). The auditory stimulus chosen was a computerised text-to-speech voice which called out participants' first names and informed them that they were dreaming (e.g., "Achilleas, you are dreaming!"). Such a stimulus is not only semantically rich, thus avoiding possible confabulations of the dreaming brain to excuse the stimulus away during the

recontextualization process, but also, the first name presentation has been shown in past research (Vallat et al., 2017; Ruby et al., 2013; Perrin, García-Larrea, Mauguière & Bastuji, 1999; Eichenlaub, Bertrand, Morlet & Ruby, 2014; Portas et al., 2000) to activate the frontotemporal regions of the brain which are key areas for LD (Voss, Holzmann, Tuin & Hobson, 2009; Dresler et al., 2012). To prevent confabulations further, the work done in chapter 5 utilised a modified version of the Targeted Lucidity Reactivation (TLR) paradigm used in Carr et al. (2020). Whereas in Carr et al. (2020) participants were trained before sleep to respond to the stimulus by turning their attention inwards and asking whether they are dreaming, we paired the stimulus presentation with the act of performing a RT. AATs were investigated by delivering the voice stimulus through a small EEG wearable, which gradually increased stimulus volume during REM epochs. It should be noted that the whole protocol was programmed by us to be delivered completely automatically without any live input from the experimenter. This included not only the stimulus presentation during sleep (upon automatic sleep staging detection of REM and subsequent adjustment of stimulus intensity), but also automatic delivery of audio explaining the study information, the delivery instructions to the participant (e.g., to inform them whether they woke up naturally or from the stimulus and to ask them to complete questionnaires), and the delivery of TLR training phases.

Due to the impact of the COVID-19 pandemic, we were unable get a large enough sample to include a control group and therefore, the AAT groups were split into two groups (low and high AAT) instead of proposed three. Nevertheless, the study was highly successful as it not only achieved 55% LD induction success (one of the highest LD induction rates in the literature), but also the ML algorithm was successfully trained to be able to predict AAT group identity with 100% success. Furthermore, analysis of the behavioural and physiological data revealed several correlates of AATs. First of all, the low AAT group unexpectedly reported

sleeping less time and being awake for longer than the high AAT, which was contrary to what sleep deprivation studies have shown in the past (Frederickson & Rechtschaffen, 1978; Rosenthal, Bishop, Krstevka, Roehrs & Roth, 1996). Furthermore, NREM delta power was decreased in low AAT group when compared to the high AAT group, again coming in contrast with sleep deprivation studies, which show that NREM delta power increases following prolonged waking duration in humans (Gent et al., 2020; Dijk, Beersma & Daan, 1997; Dijk et al., 1990) and animals (Gent et al., 2020; Franken, Chollet & Tafti, 2001; Jones, Vyazovskiy, Cirelli, Tononi & Benca, 2008; Martinez-Gonzalez, Lesku & Rattenbor, 2008; Franken, Tobler & Borbely, 1991). Therefore, these results are suggestive of a non-linear relationship between previous awakening duration and AATs (and subsequently EEG changes), as none of our participants were awake for such long duration as the ones in sleep deprivation studies. In general, delta frequency band AAT group differences were found to be directly affected by past night sleep and awake durations, as controlling for these two variables made AAT group differences disappear.

In terms of REM discrepancies between the two AAT groups, the low AAT group had lower absolute theta and beta intensity, a lower eye movement density, a greater number of positive peaks in gamma frequency bursts, and a greater number of REM MAs than the high AAT group. We postulated that the eye movement density AAT group difference is indicative of more phasic REM sleep in the high AAT group, thus explaining differences in AAT thresholds, as phasic REM has the highest SAT and the greatest inhibition of cortical processing of external stimuli (Ermis, Krakow & Voss, 2010; Lim et al., 2007; Miyauchi et al., 2009; Wehrle et al., 2007). Furthermore, we postulated that the higher number of REM MAs in the low AAT group suggests that MAs cause a decrease in the inhibition of external stimuli during REM sleep.

Overall, the thesis investigated a multitude of LDF correlates, researched the efficacy of the RT + WBTB + MILD technique and developed a highly promising external stimulation technique that utilises ML algorithms. Both RT + WBTB + MILD and the IAS technique achieved favourable LD induction rates. However, the research conducted in this thesis revealed some limitations in design or methodology that may have impacted or influenced the application or interpretation of the results. These limitations are discussed in the section below.

6.4 Limitations

Regarding chapter 3, which investigated LDF correlates, we have identified one main limitation: The survey's sample consisted only of online users of LD-related forums who are likely to be more involved with learning about LDs and using LD induction techniques. As revealed by the findings in dream attitude and beliefs, dream journaling and dream sharing were found to impact LDF. Furthermore, it is likely that users of online LD communities score higher in the OCEAN factor 'Openness to experience', which has been found to impact LDF scores positively (Hess, Schredl, Goritz, 2016). Moreover, the large meta-analysis Saunders, Roe, Smith & Clegg (2016) revealed lower LDF than the one of our sample. Thus, further work is needed to see how generalisable our findings are to the general population.

Regarding chapter 4, which investigated LDF correlates and their interplay with the efficacy of the RT + WBTB + MILD technique, we consider our greatest limitation to be the inclusion of participants who did not complete all seven days of Week 2. This could have severely affected our LD success rates. This affected our ability to directly compare our results with Aspy et al. (2017) and to investigate the impact of our modifications to their protocol. However, given the high attrition rate in Week 2 we consider our LD induction success rate to be more

than satisfactory which warrants future exploration of our protocol on a higher sample size that includes participants who completed the whole two-week protocol. Furthermore, our study revealed how the RT + WBTB + MILD technique increases measures of dream consciousness towards lucidity even in those who did not experience LDs.

Finally, for Chapter 5, as we were not able to include a control group (due to COVID-19 stopping data collection), we cannot completely discount the impact of the placebo effect on our LD induction success rate. However, it should be noted that the study was predominantly interested in AATs, and in seeing whether it is feasible to predict AATs given a set of behavioural and physiological data and in building up the ML algorithm of the IAS technique for future studies. Regarding the ML algorithm, the low sample size may have caused the 100% success of AAT group prediction to be an artifact of overfitting (Dietterich, 1995). Whilst every care was taken to minimise overfitting by applying Leave-One-Out Cross Validation (LOOCV) and by reducing the amount of features, it remains to be seen whether our ML retains its impressive accuracy when more data from larger groups of participants are used.

6.5 Future directions

When it comes to future directions of research based on the thesis findings, we propose several future directions. For example, when looking into potential LDF correlates, sending out surveys that do not specifically mention lucid dreaming, but instead are advertised as sleep-related surveys, may attract a more generalised population sample.

Furthermore, to estimate the true effect of our RT + WBTB + MILD protocol, as well as to make it more directly comparable to Aspy et al. (2017) and Aspy (2020) protocols, future

studies should aim to replicate the study with a larger sample that includes participants who went through the full two-week protocol. Furthermore future work on cognitive LD induction techniques that includes baseline weeks into their protocols should look into the possibility of adding ML to pre-test data and baseline data in order to ascertain whether accurate predictions can be made on who will experience LDs upon the first day of attempting the requested technique(s). Such a ML algorithm could aid in participant selection particularly when experienced and frequent lucid dreamers are not available to come to the sleep lab. Specifically, such a predictive ML algorithm could be used for selecting participants to come at the lab in order to conduct LD research that is not as concerned about LD induction as it is about exploring the LD state and conductive cognitive and consciousness experiments (such as the ones outlined in chapter 2).

Finally, regarding the RT + WBTB + MILD combination, individual variations of each technique have been proposed in chapter 4 that could enhance LD induction rates further. We propose that each technique used in this combination could be fine-tuned in order to increase LD induction rates further. For example, future studies could look whether there are specific times that RTs should be performed in order to increase their effectiveness and whether there is a primacy-recency effect at play. In addition, the time-point and sleep stage that participants are awoken in the WBTB method could enhance LD induction rates. Excitingly, participant sample sizes investigating this could be collected at larger numbers and at a faster rate through the use of small EEG wearable devices like the one used in chapter 5. Such devices would be given to participants to take at home and be programmed to awaken participants at specific time-point and sleep stage/cycle in order to investigate optimum wake times to perform the WBTB + MILD technique.

When it comes to the future direction of the IAS technique, chapter 5 outlined a total of twelve recommendations and ways forward that could potentially enhance the efficacy of the technique further. Out of the twelve recommendations laid out in chapter 5 we consider the five potential future directions below to be the most immediately useful for the further development of the technique:

1) Sleep studies that use traditional polysomnographic (PSG) equipment and sensors that utilise the IAS technique to induce LDs should investigate potential additional AAT correlates that could arise from the addition of EEG electrodes placed in non-frontal areas. Furthermore, the inclusion of multiple EEG sensors placed over a variety of different brain areas will facilitate EEG analyses that are not possible with the current wearable technology, such as EEG network connectivity analysis.

2) Future studies should investigate the effect of increasing the training duration of the TLR paradigm. Increasing the number of RTs conducted in response to the auditory stimulus being presented during the training phase, would not only enhance likelihood of performing the RT upon hearing it during REM sleep, but would also allow for event-related potential (ERP) analysis to be conducted. ERP analysis of stimulus presentation during the training phase could potentially reveal additional AAT correlates.

3) The study analysed physiological data that was acquired following three hours of continuous recording and which included the time that participants took to fall asleep. As such, unequal sleep EEG was collected between participants. We postulate that counting three hours (or more), following first sleep epoch detection will lead to higher uniformity of the sleep EEG data between participants improving statistical EEG

comparisons between AAT groups and likely ensure the stability of AAT predictive accuracy of current or future ML algorithms.

4) We recommend that studies that utilise the IAT technique not only try to predict and adjust the volume of the stimulus to the individual, but also the presentation rate. We postulate that adjusting both intensity and presentation rate is likely to significantly increase stimulus incorporation rates (and hence LD induction rates).

5) Finally, future studies that use IAT or aspects of it, should include a control group in order to account for possible placebo effect.

6.6 Final summary

The thesis had three goals overall. The first goal of the thesis was to first look into individual differences in LDF to see how they impact lucid dream induction. To achieve this, chapter 3 investigated a variety of LDF correlates and subsequently chapter 4 investigated their impact on LD induction rates following the practise of the RT + WBTB + MILD technique. The second goal of the thesis was to develop and investigate the efficacy of a novel auditory stimulation technique that combines aspects of cognitive techniques and utilises ML algorithms to adjust stimulus properties to the individual. The third goal was to investigate the efficacy of audio guided versions of cognitive/external stimulation techniques as well as the addition of guided written materials. The purpose of this goal was to implement such automatization processes in future LD induction protocols that could be delivered through a sleep wearable device and app.

Chapter 3 investigated a variety of potential individual differences in LDF. Results from the study revealed that those with higher LDF do not only remember having dreamt more frequently but are also able to recall dream content more completely than those with low LDF. Those who reported high LDF exhibited higher cognitive and metacognitive ability than those with low LDF. Specifically, participants with higher prospective and retrospective memory, higher mindfulness and need for cognition, were more likely to report higher LDF. These results support the Continuity Hypothesis (Domhoff, 1996) which postulates that there exists a level of continuity between waking meta/cognition and dream meta/cognition. Results in dream attitudes/beliefs and practises revealed that having positive attitudes beliefs about dreams and engaging in dream practises, such as dream journaling and sharing/talking about their dreams with others, were correlated with higher LDF. Moreover, these LDF correlates were revealed to be the driving forces behind gender differences where it was found that women have higher LDF on average than men. Sleep quality measures revealed that those with higher intranight awakenings were more likely to report high LDF, suggesting a link to the mode (increased cortical activation) through which the WBTB method increases likelihood of LD (Smith & Blagrove, 2015). Questionnaires relating to LD technique practises, revealed that practising LD techniques increases LDF, showcasing that LD is indeed a trainable phenomenon that can be induced even in those who have never experienced spontaneous LDs. The survey in chapter 3 that looked into the use of different types of LD techniques, revealed that the RT, WBTB and MILD techniques explored in the following chapter were among the most frequently used and were considered the most efficacious in inducing LDs.

Based on this finding, as well as past findings by Aspy et al. (2017) and Aspy (2020), the RT + WBTB + MILD technique was chosen to be investigated in an online field study. The study utilised a similar protocol to Aspy et al (2017), opting to investigate the efficacy of the RT +

WBTB + MILD combination through a two-week protocol (first a baseline week and the a week of attempting techniques) and used all the questions in their protocol. Moreover, the study included a variety of additional questions deemed as important to include based on the previous chapter LDF correlates. To enquire about shifts in dream consciousness the study utilised the 8 factor LuCiD questionnaire (Voss et al., 2013). Furthermore, the study departed from Aspy et al's. (2017) protocol by including an audio guided progressive relaxation technique and MILD script, and by modifying the rehearsal and visualisation part of the MILD technique through the addition of dream sign work (Levitan, 1992). Overall, in the study 41.07% of participants achieved at least one LD during week 2, lower than the 53.2% LD induction success rate reported in Aspy et al. (2017). However, this cannot be attributed to the modifications of their protocol as unlike in Aspy et al. (2017), our analyses included participants who dropped out before completing all seven days of Week 2. Furthermore, the study revealed several correlates that were described in detail in chapter 4 and summarised above in this chapter. An important finding that stood out was that we demonstrated that aspects of dream consciousness during the 2nd week increased when compared to the baseline week, regardless of whether participants achieved dream lucidity in week 2. This suggests that this combination of techniques is successful at shifting dream consciousness regardless of LD experience.

In chapter 5 a new external stimulation technique called the Individualised Auditory Stimulation (IAS) technique was developed that was discussed in detail in chapter 5 and summarised in this chapter above. In the study a small wearable research-grade EEG device with a minimal (user-friendly) number of frontal EEG sensors was used (the Hypnodyne ZMax) to investigate whether LDs could be induced without requiring traditional PSG equipment. The purpose of the study was to advance external stimulation techniques by

proposing and evaluating a novel external stimulation technique, the Individualised Auditory Stimulation (IAS) technique, powered by ML algorithms. The IAS technique aims to predict AATs and subsequently to adjust stimulus properties to the individual to enhance stimulus dream incorporation and LD induction rates. It trained participants in TLR-like protocol (modified from Carr et al., 2020) to respond to the stimulus by performing an RT in order to, condition an RT response upon hearing the stimulus in dream sleep. The IAS technique uses participants' first names in order to affect brain activity favourably in areas related to the experience of having an LD (Voss, Holzmann, Tuin & Hobson, 2009; Dresler et al., 2012). The study achieved 55% LD induction success and the ML algorithm that was developed was able to retrospectively predict with 100% accuracy AAT group membership (low vs high AAT). Moreover, a multitude of behavioural and physiological differences between the two AAT groups were uncovered in all sleep stages except NREM 2. These were described in detail in chapter 5 and summarised in this chapter above. Important AAT membership variables were the duration of being awake prior to the sleep study night and previous night sleep duration. These two variables affect delta band activity in a variety of sleep stages and in general, delta band activity was found to be a consistent marker of AATs. Overall, a variety of EEG band differences between the two AAT groups were found in all sleep stages except NREM 2. Moreover, during REM sleep a higher number of REMs and higher MA density was associated with lowered AATs These differences, which are explained in depth in chapter 5 are thought to decrease thalamic gating of external stimuli during REM sleep. Finally, we consider that the use of the sleep wearable device in the study and the successful complete automatization of the protocol through audio-guided materials and automatic device responses to participant actions, satisfied the thesis goal to demonstrate that our research findings could be implemented into a commercial, user-friendly LD sleep-wearable.

In conclusion, the work carried out in this thesis uncovered a variety of LDF correlates and effectively investigated their impact on LD induction success. Furthermore, both the modified version of the RT + WBTB + MILD and the results of the IAS study gave highly promising results, both in terms of LD induction success and also in the prediction of AATs. These results warrant future investigation and further development. Both the protocols that were developed and studied in this work could easily be implemented in a future LD-focused sleep wearable and app.

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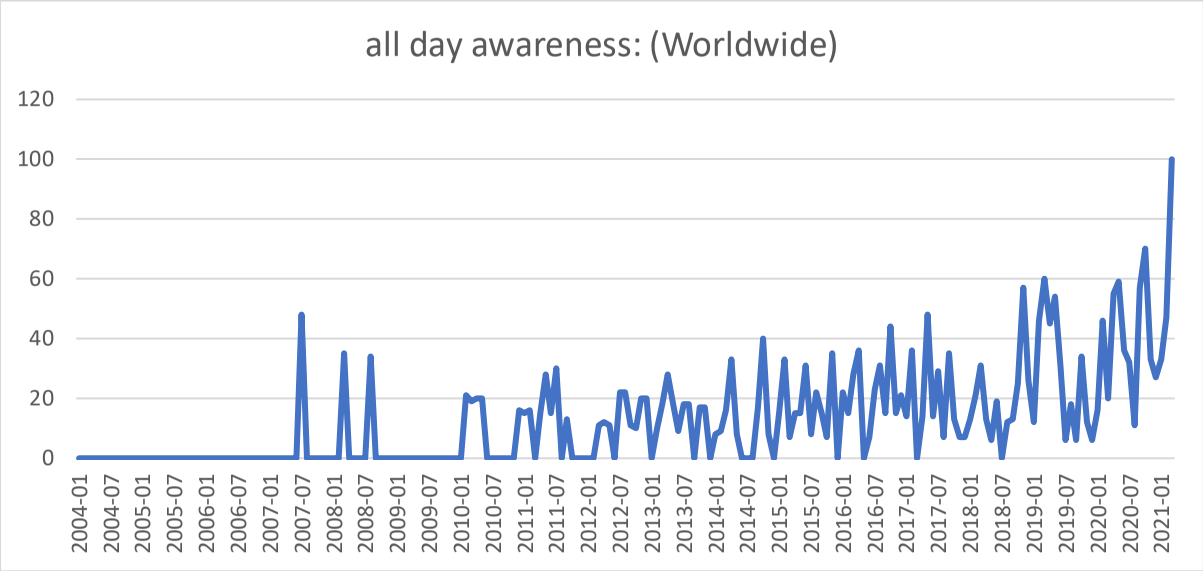
Appendices

Survey no	1 (N = 124)	2 (N = 62)	3 (N = 893)
Questions			
Demographics	X	X	X
Pittsburgh Sleep Quality Index (PSQI)	X	X	X
Prospective and Retrospective Memory Questionnaire (PRMQ)	X	X	X
Need For Cognition	X	X	X
Five Facets of Mindfulness (FFMQ)	X	X	X
Manheim Dream questionnaire (MADRE)	X	X	X
LD technique practice questions		X	X
Lucid Dream Skills Questionnaire (LUSK)		X	X
Dream Recall Completeness (DRC)			X

Appendix 3. 1 Table showing the number of participants who completed each of the three surveys and the types of questionnaires used in each.

Appendix 3.2. Google trends search revealing worldwide popularity of the term 'all day awareness', dated from 2004 to January 2021



Appendix 4.1. The dream sign (dream scenario incongruences to waking life) categories as outlined by Levitan (1992). These are split into ego, character, object and setting related dream signs	
EGO DREAM SIGNS	
Form - I was in a different body than usual, or my body was distorted	
Role - I was playing a role of other than my normal waking self	
Action - I did something unlikely or impossible than in waking life	
Perception - I was able to see, hear, feel things in a different way that usual	
Thought - I had a dreamlike thought or altered the dream events with thought	
Emotion - I experienced unusually intense emotions	
Sexual - I felt sexually aroused or felt sensations in the erogenous area	
Out of Body - I felt sensations as if "out of body"	
Body Sense - I felt unusual sensation on or in my body	
Paralysis - I felt unable to move	
CHARACTER DREAM SIGNS	
Form - A dream person is different than normal, oddly formed, or strangely dressed	
Role - A dream person is playing a role different than in waking life	
Action - A dream person does something unlikely or impossible in waking life	
Place – A dream person is in a place where he or she is unlikely to be in waking life	
OBJECT DREAM SIGNS	
Form - A dream thing is strangely built, or doesn't exist in waking life	
Action - A dream thing does something unlikely or impossible in waking life	
Place - A dream thing is in a place where it is unlikely to be in waking life	
SETTING DREAM SIGNS	
Form - The place where the dream occurs is oddly constructed or impossible	
Place - Dream occurs in a place where I am unlikely to be in waking life	
Time - Dream occurs either in the past or in some projected future	

Appendix 4.2. Audio guided progressive relaxation and MILD technique transcript

Introduction transcript

Before we start, please lay down facing the ceiling and prepare yourself for sleep. If you haven't closed your eyes it is now time to do so.

Progressive relaxation technique transcript

We'll begin by progressively relaxing your body. This is to slowly bring you into an optimum state. This step is crucial before practising MILD.

I would like you to gently bring your focus to your body. Notice how your body feels on the surface you are lying. Take a deep breath, feeling your abdomen rise, and hold for a few seconds..

Now exhale slowly.

As you breathe in again notice your stomach rising and your lungs filling with air.

Now exhale slowly, and as you do feel all tension being released and flowing out of your body

And again inhale…. And exhale...

Feel your body relaxing more and more with each breath you take.

The next step is to progressively relax your muscles, further leading you into a deep state of relaxation.

Remember, if your mind begins to wander, gently bring your focus back to the sound of my voice, and your body.

As we go through each step, remember to keep breathing.

Begin by raising your eyebrows as high as you can, feel the muscles in your forehead tighten as you do so.

Hold for about five seconds, and let go, releasing all tension. Take a moment to appreciate the release of tension from your forehead

Now smile widely and hold, feeling the tension of your lips and cheeks.

And release… Feel the softness in your face as your cheeks and lips relax.

Next, squint your eyelids tightly shut, creating tension in your eye muscles. Hold for five seconds and….

Release…..

Pull your head back gently and hold

Release, feeling the tension on your neck melting away

Feel the weight of your relaxed head and neck sinking in [5 seconds pause]

Breath in…. And breathe out

In… Let go of all stress….

...and out...

Now, clench your fists tightly taking care not to overly strain your hand. Hold….

….And release….

Slowly begin flexing your biceps, feeling the buildup of tension as you flex.

And release… Enjoy the feeling of limpness in your arms

Begin tightening your triceps by extending your arms out and locking your elbows.

Hold for five seconds….. and release

Now lift your shoulders upwards towards your ears and hold….

Now release… Notice how heavy your shoulders now feel

Tense your upper back by pulling your shoulders back making your shoulder blades touch.

Hold for about 5 seconds, and release.

Now take in a deep breath, feeling your chest tightening as you fill your lungs with air.

...And exhale, slowly blowing out all the tension…

Tighten your stomach muscles by sucking in and hold

And release…..

Gently arch your lower back, hold…. , and relax….

Notice how your upper body feels as it's letting go of the tension and stress…

Now begin tightening your hips and hold…..

...release, imagining your hips loosening

Now press your knees together, as if you were holding a small ball between them . Hold for about 5 seconds…and release. Feel your thighs relaxing as you release tension

Flex your feet, pulling your toes towards you and hold. Feel the tension in your calves. Now relax, feeling the weight of your legs sinking down.

Now curl your toes under, and hold…. Release…..

Feel the wave of relaxation slowly spreading through your body beginning at your head and going all the way down to your feet. Feel the weight of your relaxed body. Breathe in…and out…in…out….in…out.

<u>Guided MILD technique transcript</u>

I would like us now to begin our guided MILD meditation. Please assume the position you feel comfortable sleeping in.

Remember - The MILD technique requires you to do three steps. First: you must rehearse a dream, preferably the one you had before waking up. While rehearsing your dream you must then focus on your intention to remember that you are dreaming, while visualizing becoming lucid.

I would like you to recall the dream you had just before you woke up. Try to recall as many details as possible from your dream. Visualize what you saw, felt and thought. If you woke up with no memory of dreaming then recall a recent dream you've had that you remember.

Now I would like you to concentrate single-mindedly on your intention to remember to recognize that you are dreaming. Tell yourself the following; “Next time I’m dreaming, I will remember I’m dreaming”. Focus on your conviction to achieve this goal. Narrow your thoughts to this idea alone.

If you find yourself thinking about anything else, just let go of these thoughts and bring your mind back to your intention to remember.

While focusing on your intention to become lucid, imagine that you are back in the dream from which you have just awakened, but this time you recognize that it is a dream.

Think back to the dream signs questionnaire you have just completed. Choose a dream sign in the experience; when you see it, say to yourself “I’m dreaming!”. Then visualize performing a reality check.

After the tape is finished you should do this for each dream sign that you identified upon waking up. If you can remember dream signs from previous nights you can rehearse them as well.

Repeat the intention and visualization steps until your intention is set, then let yourself fall asleep. If, while falling asleep, you find yourself thinking of anything else, repeat the procedure so that the last thing in your mind before falling asleep is your intention to remember to recognize the next time you are dreaming.

You are now free to practice the MILD technique by yourself… Keep practicing MILD until you fall asleep. Goodnight!

Appendix 5.1. List of database features that went through each of the three feature selection algorithms. Database features are in descending order of PPS score feature. First the PPS score-based feature selection algorithm was applied (Post-PPS), followed by the SelectPercentile (Post-SelectPercentile), Recursive Feature Elimination (Post-RFE) and VarianceThreshold (Post-VarianceThreshold) feature selection algorithms. X denotes the features that remained at each stage.

Original database features	**Post-PPS**	**Post-Select Percentile**	**Post-RFE**	**Post-Variance Threshold**
MACROSTRUCTURE_LATENCY_N3	**x**			
LASTNIGHT_SLEEP_DURATION	**x**	**x**	**x**	x
THREEHRS.GAMMA.Symmetry.N3.AF7	**x**			
RS.Delta.AF8.ABS	**x**			
RS.Theta.AF7.ABS	**x**			
RS.Beta.AF7.ABS	**x**			
MICROAROUSALS.REM	**x**	**x**	**x**	x
MACROSTRUCTURE_DURATION_N2	**x**			
RS.Count.AF8.DELTA.CHARACTERISTICS	**x**			
RS.Amplitude.AF8.THETA.CHARACTERISTICS	**x**			
THREEHRS.Theta.N3.AF7.ABS	**x**			
THREEHRS.Alpha.R.AF7.ABS	**x**			
THREEHRS.Beta.N1.AF8.ABS	**x**			
THREEHRS.BETA.Symmetry.N1.AF7	**x**	**x**	**x**	
THREEHRS.DELTA.Density.N3.AF7	**x**			
THREEHRS.GAMMA.Density.N1.AF8	**x**	**x**	**x**	x
THREEHRS.GAMMA.Frequency.N1.AF8	**x**			
THREEHRS.THETA.Count.N1.AF8	**x**			
MICROAROUSALS.LIGHT	**x**			
RS.Beta.AF8.ABS	**x**			
RS.Symmetry.AF8.DELTA.CHARACTERISTICS	**x**			
MACROSTRUCTURE_LATENCY_N1	**x**			
MACROSTRUCTURE_SOL	**x**			
MACROSTRUCTURE_SPT	**x**			
THREEHRS.Theta.N1.AF7.ABS	**x**			

THREEHRS.Theta.N1.AF8.ABS	**x**			
THREEHRS.Gamma.N3.AF7.REL	**x**	**x**	**x**	
THREEHRS.DELTA.Symmetry.R.AF8	**x**			
THREEHRS.GAMMA.Density.N1.AF7	**x**	**x**		
THREEHRS.GAMMA.Oscillations.R.AF7	**x**			
THREEHRS.GAMMA.Symmetry.R.AF8	**x**			
THREEHRS.THETA.Density.N3.AF7	**x**			
Gender	**x**			
MACROSTRUCTURE_TST	**x**			
RS.TotalAbsPow.AF7.ABS	**x**			
RS.Duration.AF7.DELTA.CHARACTERISTICS	**x**			
RS.Amplitude.AF7.THETA.CHARACTERISTICS	**x**			
RS.RMS.AF7.THETA.CHARACTERISTICS	**x**			
MACROSTRUCTURE_SE	**x**			
THREEHRS.Delta.N1.AF7.ABS	**x**	**x**		
THREEHRS.Delta.N1.AF8.ABS	**x**			
THREEHRS.Theta.R.AF7.ABS	**x**			
THREEHRS.Alpha.N1.AF7.ABS	**x**			
THREEHRS.Beta.N3.AF7.ABS	**x**			
THREEHRS.Beta.R.AF8.ABS	**x**			
THREEHRS.TotalAbsPow.N3.AF7.ABS	**x**			
THREEHRS.Delta.N1.AF8.REL	**x**			
THREEHRS.SW.Duration.AF7.N23	**x**			
THREEHRS.SW.Frequency.AF7.N23	**x**			
THREEHRS.BETA.Density.N1.AF7	**x**			
THREEHRS.BETA.Duration.R.AF7	**x**			
THREEHRS.DELTA.Duration.N3.AF7	**x**			
THREEHRS.DELTA.Frequency.R.AF7	**x**			
THREEHRS.GAMMA.Duration.N1.AF7	**x**			
THREEHRS.GAMMA.Duration.R.AF8	**x**			
THREEHRS.GAMMA.Amplitude.N3.AF7	**x**			
THREEHRS.GAMMA.Frequency.N3.AF7	**x**			

TIME_SPENT_AWAKE	**x**			
RS.TotalAbsPow.AF8.ABS	**x**			
RS.Count.AF7.DELTA.CHARACTERISTICS	**x**			
RS.Duration.AF8.DELTA.CHARACTERISTICS	**x**			
RS.Frequency.AF8.DELTA.CHARACTERISTICS	**x**			
RS.Frequency.AF7.THETA.CHARACTERISTICS	**x**			
RS.Oscillations.AF7.THETA.CHARACTERISTICS	**x**			
RS.Frequency.AF7.BETA.CHARACTERISTICS	**x**			
MACROSTRUCTURE_PERCENTAGE_N2	**x**			
MACROSTRUCTURE_LATENCY_N2	**x**			
MACROSTRUCTURE_LATENCY_REM	**x**			
THREEHRS.Delta.N3.AF7.ABS	**x**			
THREEHRS.Alpha.N1.AF8.ABS	**x**			
THREEHRS.Gamma.N1.AF7.ABS	**x**			
THREEHRS.Gamma.N3.AF8.ABS	**x**			
THREEHRS.BETA.Density.R.AF8	**x**			
THREEHRS.BETA.Duration.N3.AF7	**x**			
THREEHRS.DELTA.Density.N3.AF8	**x**			
THREEHRS.DELTA.Duration.R.AF8	**x**			
THREEHRS.DELTA.Frequency.N1.AF8	**x**			
THREEHRS.DELTA.Frequency.R.AF8	**x**			
THREEHRS.GAMMA.Duration.N1.AF8	**x**			
THREEHRS.GAMMA.Duration.R.AF7	**x**			
THREEHRS.GAMMA.RMS.R.AF8	**x**			
THREEHRS.GAMMA.Frequency.R.AF7	**x**			
THREEHRS.GAMMA.Oscillations.N3.AF8	**x**			
THREEHRS.THETA.Density.R.AF8	**x**			
THREEHRS.THETA.Duration.N1.AF7	**x**			
THREEHRS.THETA.Amplitude.R.AF7	**x**			
THREEHRS.THETA.Frequency.N3.AF8	**x**			

MICROAROUSALS.TOTAL	**x**			
MACROSTRUCTURE_TIB	**x**			
RS.Delta.AF7.REL	**x**			
RS.Theta.AF7.REL	**x**			
RS.RMS.AF7.DELTA.CHARACTERISTICS	**x**			
RS.Symmetry.AF7.DELTA.CHARACTERISTICS	**x**			
RS.Count.AF8.THETA.CHARACTERISTICS	**x**			
RS.Duration.AF8.THETA.CHARACTERISTICS	**x**			
RS.RMS.AF8.THETA.CHARACTERISTICS	**x**			
THREEHRS.Theta.N3.AF8.ABS	**x**			
THREEHRS.Beta.N1.AF7.ABS	**x**			
THREEHRS.Gamma.R.AF7.ABS	**x**			
THREEHRS.TotalAbsPow.N1.AF7.ABS	**x**	**x**		
THREEHRS.Alpha.R.AF7.REL	**x**			
THREEHRS.Alpha.R.AF8.REL	**x**			
THREEHRS.SW.Count.AF7.N23	**x**			
THREEHRS.SW.ValNegPeak.AF8.N23	**x**			
THREEHRS.SW.ValPosPeak.AF8.N23	**x**			
THREEHRS.SW.PTP.AF8.N23	**x**			
THREEHRS.REMS.Density	**x**			
THREEHRS.REMS.ROCAbsValPeak	**x**			
THREEHRS.REMS.LOCAbsRiseSlope	**x**			
THREEHRS.BETA.Density.R.AF7	**x**			
THREEHRS.BETA.Frequency.N3.AF8	**x**			
THREEHRS.BETA.Frequency.R.AF8	**x**			
THREEHRS.BETA.Oscillations.R.AF7	**x**			
THREEHRS.DELTA.Count.R.AF7	**x**			
THREEHRS.DELTA.Frequency.N1.AF7	**x**			
THREEHRS.GAMMA.Amplitude.N1.AF7	**x**			
THREEHRS.GAMMA.RMS.N1.AF7	**x**			
THREEHRS.GAMMA.RMS.N3.AF7	**x**			
THREEHRS.GAMMA.Symmetry.R.AF7	**x**			

THREEHRS.THETA.Density.N3.AF8	**x**			
THREEHRS.THETA.RMS.R.AF7	**x**			
THREEHRS.THETA.Frequency.N3.AF7	**x**	**x**		
THREEHRS.THETA.Symmetry.N3.AF7	**x**			
MICROAROUSALS.SWS	**x**			
RS.Delta.AF8.REL	**x**			
RS.Theta.AF8.REL	**x**			
RS.Beta.AF8.REL	**x**			
RS.RMS.AF8.DELTA.CHARACTERISTICS	**x**			
RS.Amplitude.AF8.BETA.CHARACTERISTICS	**x**			
RS.RMS.AF7.BETA.CHARACTERISTICS	**x**			
RS.Frequency.AF8.BETA.CHARACTERISTICS	**x**			
RS.Symmetry.AF7.BETA.CHARACTERISTICS	**x**			
MACROSTRUCTURE_PERCENTAGE_N1	**x**			
MACROSTRUCTURE_PERCENTAGE_N3	**x**			
MACROSTRUCTURE_PERCENTAGE_NREM	**x**			
THREEHRS.Alpha.R.AF8.ABS	**x**			
THREEHRS.Gamma.N3.AF7.ABS	**x**			
THREEHRS.TotalAbsPow.N3.AF8.ABS	**x**			
THREEHRS.TotalAbsPow.R.AF8.ABS	**x**			
THREEHRS.Delta.N3.AF8.REL	**x**			
THREEHRS.Delta.R.AF7.REL	**x**			
THREEHRS.Theta.N3.AF7.REL	**x**			
THREEHRS.Theta.N3.AF8.REL	**x**			
THREEHRS.Alpha.N1.AF7.REL	**x**			
THREEHRS.Gamma.N1.AF7.REL	**x**			
THREEHRS.Gamma.N1.AF8.REL	**x**			
THREEHRS.Gamma.R.AF8.REL	**x**			
THREEHRS.REMS.Count	**x**			
THREEHRS.BETA.Duration.N1.AF8	**x**			
THREEHRS.BETA.Duration.N3.AF8	**x**			
THREEHRS.BETA.Amplitude.N1.AF7	**x**			
THREEHRS.BETA.Amplitude.N1.AF8	**x**			

THREEHRS.BETA.RMS.R.AF8	**x**			
THREEHRS.BETA.Oscillations.R.AF8	**x**			
THREEHRS.BETA.Symmetry.N3.AF8	**x**			
THREEHRS.BETA.Symmetry.R.AF7	**x**			
THREEHRS.DELTA.Count.N3.AF7	**x**			
THREEHRS.DELTA.Count.R.AF8	**x**			
THREEHRS.DELTA.Density.N1.AF7	**x**			
THREEHRS.DELTA.Density.N1.AF8	**x**			
THREEHRS.DELTA.Duration.N1.AF8	**x**			
THREEHRS.DELTA.Amplitude.N1.AF7	**x**			
THREEHRS.DELTA.RMS.R.AF8	**x**			
THREEHRS.DELTA.Oscillations.N3.AF8	**x**			
THREEHRS.DELTA.Oscillations.R.AF8	**x**			
THREEHRS.GAMMA.Count.N1.AF7	**x**			
THREEHRS.GAMMA.Count.N3.AF8	**x**			
THREEHRS.GAMMA.Count.R.AF8	**x**			
THREEHRS.GAMMA.Density.R.AF8	**x**			
THREEHRS.GAMMA.Duration.N3.AF7	**x**			
THREEHRS.GAMMA.Amplitude.N1.AF8	**x**			
THREEHRS.GAMMA.Amplitude.N3.AF8	**x**			
THREEHRS.GAMMA.Amplitude.R.AF8	**x**			
THREEHRS.GAMMA.Frequency.N3.AF8	**x**			
THREEHRS.GAMMA.Oscillations.N1.AF8	**x**			
THREEHRS.THETA.Density.N1.AF8	**x**			
THREEHRS.THETA.Duration.N3.AF7	**x**			
THREEHRS.THETA.Duration.N3.AF8	**x**			
THREEHRS.THETA.Duration.R.AF8	**x**			
THREEHRS.THETA.Amplitude.N1.AF8	**x**			
THREEHRS.THETA.RMS.N3.AF7	**x**			
THREEHRS.THETA.Frequency.R.AF7	**x**			
THREEHRS.THETA.Symmetry.R.AF8	**x**			
MICROAROUSALS.NREM				
MICROAROUSALS.LIGHT.DENSITY				

MICROAROUSALS.SWS.DENSITY				
MICROAROUSALS.NREM.DENSITY				
MICROAROUSALS.REM.DENSITY				
MICROAROUSALS.TOTAL.DENSITY				
MACROSTRUCTURE_DURATION_N1				
MACROSTRUCTURE_DURATION_N3				
MACROSTRUCTURE_DURATION_REM				
RS.Delta.AF7.ABS				
RS.Theta.AF8.ABS				
RS.Beta.AF7.REL				
RS.Amplitude.AF7.DELTA.CHARACTERISTICS				
RS.Amplitude.AF8.DELTA.CHARACTERISTICS				
RS.Frequency.AF7.DELTA.CHARACTERISTICS				
RS.Oscillations.AF7.DELTA.CHARACTERISTICS				
RS.Oscillations.AF8.DELTA.CHARACTERISTICS				
RS.Count.AF7.THETA.CHARACTERISTICS				
RS.Duration.AF7.THETA.CHARACTERISTICS				
RS.Frequency.AF8.THETA.CHARACTERISTICS				
RS.Oscillations.AF8.THETA.CHARACTERISTICS				
RS.Symmetry.AF7.THETA.CHARACTERISTICS				
RS.Symmetry.AF8.THETA.CHARACTERISTICS				
RS.Count.AF7.BETA.CHARACTERISTICS				
RS.Count.AF8.BETA.CHARACTERISTICS				
RS.Duration.AF7.BETA.CHARACTERISTICS				

RS.Duration.AF8.BETA.CHARACTERISTICS				
RS.Amplitude.AF7.BETA.CHARACTERISTICS				
RS.RMS.AF8.BETA.CHARACTERISTICS				
RS.Oscillations.AF7.BETA.CHARACTERISTICS				
RS.Oscillations.AF8.BETA.CHARACTERISTICS				
RS.Symmetry.AF8.BETA.CHARACTERISTICS				
MACROSTRUCTURE_PERCENTAGE_REM				
MACROSTRUCTURE_DURATION_NREM				
MACROSTRUCTURE_SME				
MACROSTRUCTURE_WASO				
THREEHRS.Delta.N3.AF8.ABS				
THREEHRS.Delta.R.AF7.ABS				
THREEHRS.Delta.R.AF8.ABS				
THREEHRS.Theta.R.AF8.ABS				
THREEHRS.Alpha.N3.AF7.ABS				
THREEHRS.Alpha.N3.AF8.ABS				
THREEHRS.Beta.N3.AF8.ABS				
THREEHRS.Beta.R.AF7.ABS				
THREEHRS.Gamma.N1.AF8.ABS				
THREEHRS.Gamma.R.AF8.ABS				
THREEHRS.TotalAbsPow.N1.AF8.ABS				
THREEHRS.TotalAbsPow.R.AF7.ABS				
THREEHRS.Delta.N1.AF7.REL				
THREEHRS.Delta.N3.AF7.REL				
THREEHRS.Delta.R.AF8.REL				
THREEHRS.Theta.N1.AF7.REL				
THREEHRS.Theta.N1.AF8.REL				
THREEHRS.Theta.R.AF7.REL				
THREEHRS.Theta.R.AF8.REL				
THREEHRS.Alpha.N1.AF8.REL				
THREEHRS.Alpha.N3.AF7.REL				

THREEHRS.Alpha.N3.AF8.REL				
THREEHRS.Beta.N1.AF7.REL				
THREEHRS.Beta.N1.AF8.REL				
THREEHRS.Beta.N3.AF7.REL				
THREEHRS.Beta.N3.AF8.REL				
THREEHRS.Beta.R.AF7.REL				
THREEHRS.Beta.R.AF8.REL				
THREEHRS.Gamma.N3.AF8.REL				
THREEHRS.Gamma.R.AF7.REL				
THREEHRS.SW.Count.AF8.N23				
THREEHRS.SW.Duration.AF8.N23				
THREEHRS.SW.ValNegPeak.AF7.N23				
THREEHRS.SW.ValPosPeak.AF7.N23				
THREEHRS.SW.PTP.AF7.N23				
THREEHRS.SW.Slope.AF7.N23				
THREEHRS.SW.Slope.AF8.N23				
THREEHRS.SW.Frequency.AF8.N23				
THREEHRS.SW.PhaseAtSigmaPeak.AF7.N23				
THREEHRS.SW.PhaseAtSigmaPeak.AF8.N23				
THREEHRS.SW.ndPAC.AF7.N23				
THREEHRS.SW.ndPAC.AF8.N23				
THREEHRS.REMS.Duration				
THREEHRS.REMS.LOCAbsValPeak				
THREEHRS.REMS.ROCAbsRiseSlope				
THREEHRS.REMS.LOCAbsFallSlope				
THREEHRS.REMS.ROCAbsFallSlope				
THREEHRS.BETA.Count.N1.AF7				
THREEHRS.BETA.Count.N1.AF8				
THREEHRS.BETA.Count.N3.AF7				
THREEHRS.BETA.Count.N3.AF8				
THREEHRS.BETA.Count.R.AF7				
THREEHRS.BETA.Count.R.AF8				
THREEHRS.BETA.Density.N1.AF8				

THREEHRS.BETA.Density.N3.AF7				
THREEHRS.BETA.Density.N3.AF8				
THREEHRS.BETA.Duration.N1.AF7				
THREEHRS.BETA.Duration.R.AF8				
THREEHRS.BETA.Amplitude.N3.AF7				
THREEHRS.BETA.Amplitude.N3.AF8				
THREEHRS.BETA.Amplitude.R.AF7				
THREEHRS.BETA.Amplitude.R.AF8				
THREEHRS.BETA.RMS.N1.AF7				
THREEHRS.BETA.RMS.N1.AF8				
THREEHRS.BETA.RMS.N3.AF7				
THREEHRS.BETA.RMS.N3.AF8				
THREEHRS.BETA.RMS.R.AF7				
THREEHRS.BETA.Frequency.N3.AF7				
THREEHRS.BETA.Frequency.R.AF7				
THREEHRS.BETA.Oscillations.N1.AF7				
THREEHRS.BETA.Oscillations.N1.AF8				
THREEHRS.BETA.Oscillations.N3.AF7				
THREEHRS.BETA.Oscillations.N3.AF8				
THREEHRS.BETA.Symmetry.N1.AF8				
THREEHRS.BETA.Symmetry.N3.AF7				
THREEHRS.BETA.Symmetry.R.AF8				
THREEHRS.DELTA.Count.N1.AF7				
THREEHRS.DELTA.Count.N1.AF8				
THREEHRS.DELTA.Count.N3.AF8				
THREEHRS.DELTA.Density.R.AF7				
THREEHRS.DELTA.Density.R.AF8				
THREEHRS.DELTA.Duration.N1.AF7				
THREEHRS.DELTA.Duration.N3.AF8				
THREEHRS.DELTA.Duration.R.AF7				
THREEHRS.DELTA.Amplitude.N1.AF8				
THREEHRS.DELTA.Amplitude.N3.AF7				
THREEHRS.DELTA.Amplitude.N3.AF8				

THREEHRS.DELTA.Amplitude.R.AF7				
THREEHRS.DELTA.Amplitude.R.AF8				
THREEHRS.DELTA.RMS.N1.AF7				
THREEHRS.DELTA.RMS.N1.AF8				
THREEHRS.DELTA.RMS.N3.AF7				
THREEHRS.DELTA.RMS.N3.AF8				
THREEHRS.DELTA.RMS.R.AF7				
THREEHRS.DELTA.Frequency.N3.AF7				
THREEHRS.DELTA.Frequency.N3.AF8				
THREEHRS.DELTA.Oscillations.N1.AF7				
THREEHRS.DELTA.Oscillations.N1.AF8				
THREEHRS.DELTA.Oscillations.N3.AF7				
THREEHRS.DELTA.Oscillations.R.AF7				
THREEHRS.DELTA.Symmetry.N1.AF7				
THREEHRS.DELTA.Symmetry.N1.AF8				
THREEHRS.DELTA.Symmetry.N3.AF7				
THREEHRS.DELTA.Symmetry.N3.AF8				
THREEHRS.DELTA.Symmetry.R.AF7				
THREEHRS.GAMMA.Count.N1.AF8				
THREEHRS.GAMMA.Count.N3.AF7				
THREEHRS.GAMMA.Count.R.AF7				
THREEHRS.GAMMA.Density.N3.AF7				
THREEHRS.GAMMA.Density.N3.AF8				
THREEHRS.GAMMA.Density.R.AF7				
THREEHRS.GAMMA.Duration.N3.AF8				
THREEHRS.GAMMA.Amplitude.R.AF7				
THREEHRS.GAMMA.RMS.N1.AF8				
THREEHRS.GAMMA.RMS.N3.AF8				
THREEHRS.GAMMA.RMS.R.AF7				
THREEHRS.GAMMA.Frequency.N1.AF7				
THREEHRS.GAMMA.Frequency.R.AF8				
THREEHRS.GAMMA.Oscillations.N1.AF7				
THREEHRS.GAMMA.Oscillations.N3.AF7				

THREEHRS.GAMMA.Oscillations.R.AF8				
THREEHRS.GAMMA.Symmetry.N1.AF7				
THREEHRS.GAMMA.Symmetry.N1.AF8				
THREEHRS.GAMMA.Symmetry.N3.AF8				
THREEHRS.THETA.Count.N1.AF7				
THREEHRS.THETA.Count.N3.AF7				
THREEHRS.THETA.Count.N3.AF8				
THREEHRS.THETA.Count.R.AF7				
THREEHRS.THETA.Count.R.AF8				
THREEHRS.THETA.Density.N1.AF7				
THREEHRS.THETA.Density.R.AF7				
THREEHRS.THETA.Duration.N1.AF8				
THREEHRS.THETA.Duration.R.AF7				
THREEHRS.THETA.Amplitude.N1.AF7				
THREEHRS.THETA.Amplitude.N3.AF7				
THREEHRS.THETA.Amplitude.N3.AF8				
THREEHRS.THETA.Amplitude.R.AF8				
THREEHRS.THETA.RMS.N1.AF7				
THREEHRS.THETA.RMS.N1.AF8				
THREEHRS.THETA.RMS.N3.AF8				
THREEHRS.THETA.RMS.R.AF8				
THREEHRS.THETA.Frequency.N1.AF7				
THREEHRS.THETA.Frequency.N1.AF8				
THREEHRS.THETA.Frequency.R.AF8				
THREEHRS.THETA.Oscillations.N1.AF7				
THREEHRS.THETA.Oscillations.N1.AF8				
THREEHRS.THETA.Oscillations.N3.AF7				
THREEHRS.THETA.Oscillations.N3.AF8				
THREEHRS.THETA.Oscillations.R.AF7				
THREEHRS.THETA.Oscillations.R.AF8				
THREEHRS.THETA.Symmetry.N1.AF7				
THREEHRS.THETA.Symmetry.N1.AF8				
THREEHRS.THETA.Symmetry.N3.AF8				

THREEHRS.THETA.Symmetry.R.AF7				