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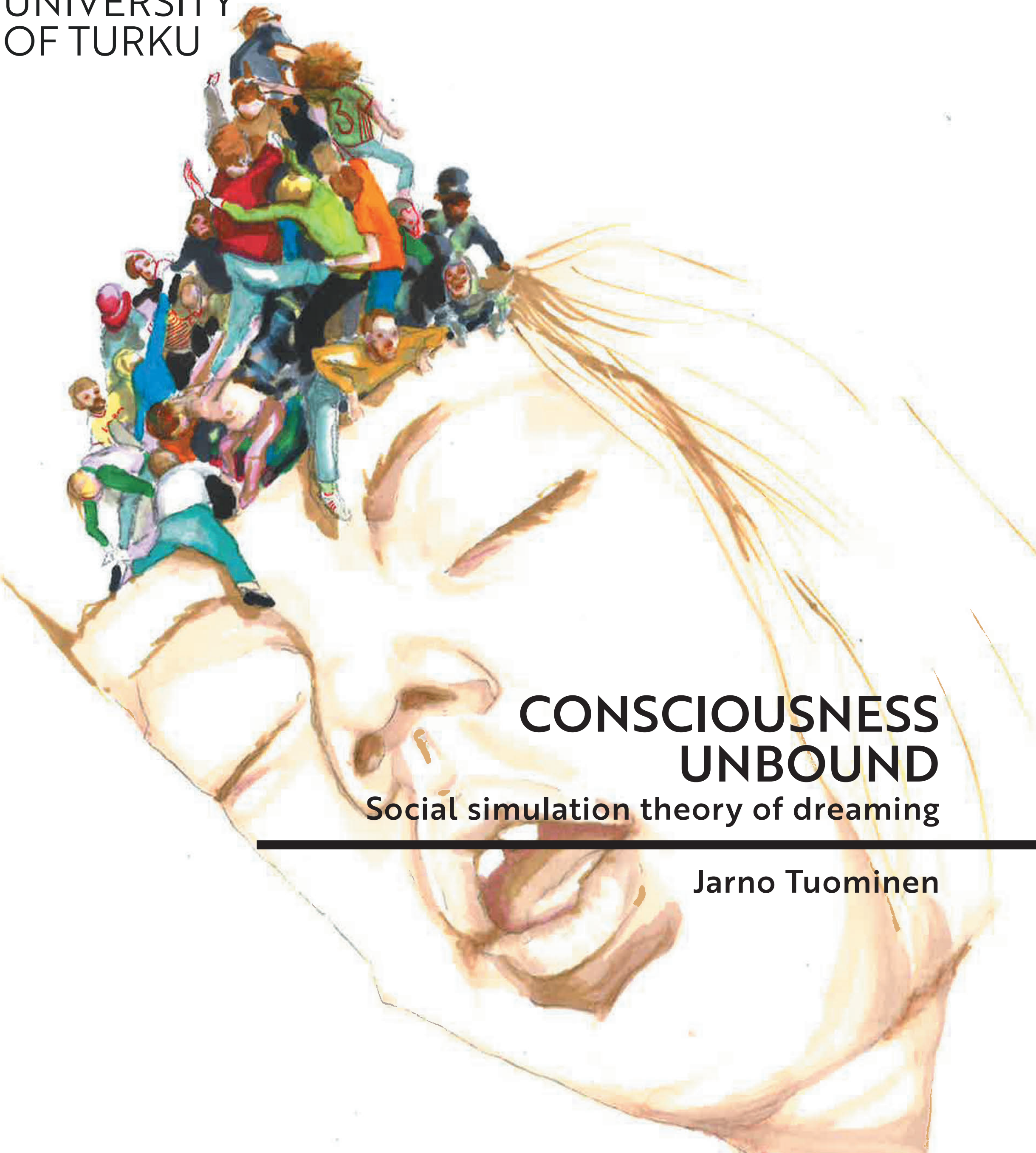

CONSCIOUSNESS UNBOUND

Social simulation theory of dreaming

Jarno Tuominen

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SARJA – SER. B OSA – TOM. 571 | HUMANIORA | TURKU 2022

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University of Turku

Faculty of Social Sciences
Department of Psychology and Speech-Language Pathology
Psychology
Doctoral Programme in Clinical Research

Supervised by

Docent, Katja Valli Department of Psychology and Speech-Language Pathology University of Turku	Professor, Antti Revonsuo Department of Psychology and Speech-Language Pathology University of Turku

Reviewed by

Professor Mark Blagrove Department of Psychology Swansea University Swansea, UK	Associate Professor Patrick McNamara Department of Neurology Boston University School of Medicine Boston, MA, US

Opponent

Professor Mark Blagrove
Department of Psychology
Swansea University
Swansea, UK

Cover Image: Jarno Tuominen

ISBN 978-951-29-8802-0 (PRINT)
ISBN 978-951-29-8803-7 (PDF)
ISSN 0082-6987 (Print)
ISSN 2343-3191 (Online)
Painosalama, Turku, Finland 2022

UNIVERSITY OF TURKU
Faculty of Social Sciences
Department of Psychology and Speech-Language Pathology
JARNO TUOMINEN: Consciousness unbound: Social Simulation Theory of dreaming
Doctoral Dissertation, 215 pp.
Doctoral Programme in Clinical Research
March 2022

ABSTRACT

Every night during sleep we experience an immersive world of dreams, woven together by our sleeping brain unbound by external stimulation. Despite considerable effort the question of *why we dream* has eluded a conclusive answer. Understanding dreams also arguably makes progress toward answering the broader question of consciousness: *why do we experience anything at all*? I attempt to illuminate these questions by concentrating on the quintessentially social nature of dreams. First, in Study I a novel theoretical account—the *Social Simulation Theory of dreaming* (SST)—is proposed, together with the first outlines of a research program for its empirical study. SST suggests the world simulation form of dreams provides clues for its function by preferentially simulating certain kinds of scenarios—namely social interactions. Second, in Studies II and III specific hypotheses derived from the SST in Study I are empirically evaluated. These provide evidence for dreams to contain more social content than corresponding waking life and to remain so even when social interactions are removed from waking life (*Sociality Bias*). Furthermore, the *Strengthening Hypothesis* that suggests dreams serve to maintain and/or increase social bonding with close others gains partial support. The *Practise and Preparation Hypothesis* gained support as dreams simulated positive interactions in one fifth of dream interactions and overall simulate complex social behaviours. The *Compensation Hypothesis* suggests dreams simulations to increase when waking social contacts are abolished, but this was not supported in the data as dream sociality remained stable despite social seclusion. When excluded from others our dreams reconfigure to decrease simulations of interactions with strangers. However, dreams during normal day-to-day life do not preferentially simulate bond-strengthening interactions with close others. In opposition to previous findings, Study II found no differences in social dream contents between either stage of sleep or time of night. In Study III a short social seclusion showed not only differences in dream content, but also in sleep structure, with an increase in REM sleep. Third, methodological development was undertaken by, both, developing a content analysis method for extracting social episodes in narrative reports (*Social Content Scale, SCS;* Study II), and by assessing the validity of a novel home sleep monitor device, the Beddit Sleep Tracker (BST). While the SCS proved useful for categorizing the social features in both studies II and III, BST failed to provide accurate sleep data as measured against a polysomnogram. Overall, the development of SST and the initial empirical evidence for some of its hypotheses brings us closer to understanding the twin problems of dreaming and consciousness.

KEYWORDS: Consciousness, Dreaming, Social simulation theory, REM sleep, NREM sleep, social seclusion

TURUN YLIOPISTO
Yhteiskuntatieteellinen tiedekunta
Psykologian ja logopedian laitos
JARNO TUOMINEN: Kahlitsematon tajunta: unennäön sosiaalisen simulaation teoria
Väitöskirja, 215 s.
Turun kliininen tohtoriohjelma
Maaliskuu 2022

TIIVISTELMÄ

Nukkuvat aivomme kehittävät joka yö ajankohtaisesta aistitiedosta riippumattoman monipuolisen ja todentuntuisen kokemuksen maailmasta—unen. Kysymykseen siitä *miksi koemme unia* ei ole yrityksistä huolimatta vielä saatu kattavaa vastausta. Unien luonteen ymmärtäminen toisi meitä todennäköisesti lähemmäs myös suuremman, tajunnan luonnetta koskevan kysymyksen ratkaisua: *miksi ylipäänsä koemme mitään*? Pyrin valottamaan näitä kysymyksiä keskittymällä erityisesti unien sosiaaliseen luonteeseen. Osatutkimuksessa I kehitämme uuden *sosiaalisen simulaation teorian* (SST) sekä esittelemme tutkimusohjelman sen väitteiden empiiriseen arviointiin. SST hyödyntää näkemystä unien maailmasimulaatiomuodosta ymmärtääkseen niiden funktiota, keskittyen erityisesti unien taipumukseen painottaa sosiaalisten tilanteiden simulointia. Osatutkimuksissa II ja III tutkimme SST:n hypoteeseja empiirisen unitutkimuksen keinoin. *Sosiaalisuusvinouma* unista poikkeuksellisen sosiaalisina kokemuksina saa vahvistusta löydöksestä, jossa unissa havaitaan olevan merkittävästi vastaavaa valvetta enemmän sosiaalisia tilanteita (II), ja vaikka sosiaalisia tilanteita ei esiintyisi arjessa, pysyy niiden määrä unissa ennallaan. Lisäksi *vahvistushypoteesi*, jonka mukaan unet vahvistavat erityisesti läheisiä ihmissuhteitamme, saa osittaista tukea. Osatutkimus III:ssa lyhyt sosiaalinen eristys johtaa muutoksiin unihahmojen luonteessa, unien alkaessa sisältää vähemmän tuntemattomien kanssa koettuja vuorovaikutustilanteita. *Harjoitushypoteesi* sai osin tukea unien simuloidessa monimutkaisia, ja viidenneksen positiivisia vuorovaikutustilanteita. *Kompensaatiohypoteesin* mukaan vuorovaikutusunet lisääntyvät arjen sosiaalisten suhteiden poistuessa, mutta tämä ei saanut tukea unisosiaalisuuden pysyessä entisellään eristyksestä huolimatta. Normaalisti unissa emme kuitenkaan erityisesti simuloi vahvistavia vuorovaikutustilanteita läheisten kanssa, eivätkä unien sosiaaliset sisällöt eroa univaiheen tai nukkumisen keston mukaan (II). Sosiaalinen eristys kuitenkin lisäsi myös REM-unen osuutta. Lopuksi, väitöskirjassa menetelmäkehitystä edistettiin sekä luomalla uusi sisällönanalyysimenetelmä sosiaalisten tilanteiden luokitteluun (SCS) että tutkimalla unta mittaavan Beddit-unimittarin (BST) tarkkuutta mitata nukkumista ja univaiheita. Siinä missä SCS osoittautui käyttökelpoiseksi menetelmäksi sosiaalisten tilanteiden kategorisointiin, BST ei kyennyt esittämään luotettavaa tietoa unimuuttujista verrattuna unipolygrafiaan. Lopputulemana, SST ja sen ensimmäisten hypoteesien tutkimus tuo meidät lähemmäs unennäön ja tajunnan kaksoisongelmien ratkaisua.

ASIASANAT: Unennäkö, sosiaalisen simulaation teoria, tajunta, tietoisuus, vilkeuni, ortouni

Acknowledgements

“...il faut continuer, je ne peux pas continuer, je vais continuer.”

Beckett, S. (1953). *L’Innomable.* Editions de Minuit, pp.213.

Sunk cost fallacy refers to a situation where the more time and resources you alot to a specific endeavour the more likely you are to continue on the effort—sometimes even to one’s detriment. The costs can be of myriad types, ranging from the financial to the social, from the emotional to the intellectual. To undertake a PhD is an exercise in this phenomenon par excellence. Having now reached the shores of this project it has come the time to thank those without whom this could and would not have been possible. It is this community that has made it all worthwhile, that have sunk my personal costs, and allowed me to emerge on the side of the subjectively positive. Thank you for being *there*.

First, the scientific, philosophical, practical and emotional support from my supervisor’s adjunct professor Katja Valli and professor Antti Revonsuo has been of integral importance, and this space cannot contain my gratitude. They have allowed me to think new things—regardless of the utility or cohesiveness of these forking paths—to become interested in a way that for me exemplifies the true academic spirit. True, it has not always been the most effective of routes, but it has had other, far more important merits. They have truly provided me a zone of proximal development far beyond this work.

Katja has exemplified a model of not only scientific rigour within the arguably porous field of sleep and dream research, but also of empathy, warmth and an attitude towards colleagues and students that is absolutely laudable. Katja has made the consciousness research nook at the University of Turku feel like home, and during the heyday of the Consciousness Research Group in the first freezing floor of the Publicum building help me maintain what can only be described as a flawless choreography to address our respective caffeine input needs. Katja, thank you for being a mentor, a supervisor, a colleague, and a friend.

Antti, the quintessential professor of consciousness, with whom every interaction is filled with nuggets of knowledge ranging from the lepidoptera to the Metaphysical

Club. It is Antti's humility and reflective weighing of even the positions and arguments opposite to his own, that has helped me find the true value of scientific discussion and ideas exchange. It is due to Antti's work on consciousness that I even applied to study psychology, and have had no need to look back since. Upon my PhD odyssey Antti has always been supportive, providing comments, ideas, recommendations in a manner that elevates rather than suppresses. I can only hope to emulate the Jamesian exemplar (even beyond the professional) you have provided.

I wish to also express my sincere gratitude to the reviewers of this thesis, professor Mark Blagrove and associate Professor Patrick McNamara. Thank you for taking the time to review my work not only during the always tight schedules of the academic term but also doing so amid a raging pandemic. The feedback was exemplary as it gave detailed and insightful commentary, while also provided encouragement and motivation to give this book the last finalizing push. I feel privileged to be a part of just such measured and thoughtful discussion with the two world-leading experts of the field. I wish to especially thank Professor Blagrove who, in addition to reviewing the thesis, has also agreed to take on the considerable task of serving as my opponent in the public defense. It is with a heavy heart I address this situation where the defense can not be carried out in person due to the pandemic situation. It is truly a sign of the times, and in a way appropriately ironic that the end of my PhD—after all delving into the topic of social interaction and their mental representations—will be finalized under restrictions on social gathering and via Zoom.

To list only the most important and close colleagues who have helped me in this endeavour and to outline their respective importance and support even in passing detail would double the printing costs of this thesis as well as substantially increasing its already considerable length. Thus, apologies for the brevity for it does not do adequate justice for you all, and I hope you are aware of the position you inhabit. Apologies also for those not listed here due to cognitive deficiencies of the author. The dramatis personae is far too long for accurate retrieval.

Thank you Dr Henri Olkoniemi (University of Oulu) for—well—everything. Ever since roaming down Hämeenkatu on the late August evenings of 2006 as larval students I have had the honour of having you as a close friend and colleague. A lot has happened, and despite considerable odds we have both been able to finalize our respective PhD's (even though I must note that on my part in actuality it seemed to require a 600 km+ distance and a florid pandemic). While to an external observer it would maybe not always seem clear that we are in fact hard at work sharing ideas, comments, or random observations while laughing too long at terrible jokes, it is beyond clear to me that as a question of making modern academia tolerable and worthwhile, your company has been of utmost importance.

Dr Nils Sandman (University if Turku) was the first colleague I was introduced to after selecting to go down this path. I still remember the situation in the far reaches of the CCN corridor, and am happy the united path did not end there. We provide an interesting dynamic, as I think it is safe to say we disagree to a considerable degree in a multitude of scientific matters—nature of human kind, free will, and computationalism to name a few—, yet I often find these discussions absolutely exhilarating and your company a joy. It is a rare talent and I salute you for it. It has been a pleasure to trot the globe with you and I hope the end of this debating-in-all-continents tradition is yet to be seen.

Dr Pilleriin Sikka (Stanford University) is a rare breed indeed. Your mix of sparkling humanity with a first-rate inquisitive scientific mind makes you an ideal colleague, friend and an overall human being. It is a privilege having had the opportunity to work with you. Your friendship has marked my PhD path and provided great memories, experiences, and discussions. Thank you for being the collective primus motor and always being ready to think ten impossible things before breakfast (or before sunrise).

Assistant professor Henry Railo (University of Turku) has provided a marked impression on my research career that I hope to keep alight into the future. Your brand of scientific impatience—the need to get to the roots of it all—has been both a theatre hook that has helped draw me back from the more implausible theoretical reaches, or alternatively has provoked new ways of thinking and ways to rigorously address the hardest to operationalize research questions. Thank you for your always curious yet adequately critical attitude. Having ended up with some hare-brained idea or another I can always trust on you to deliver useful and thoughtful feedback with compassion.

PhD candidate Roosa Kallionpää (University of Turku) for being an excellent colleague and always providing your measured comments with true warmth and empathy. It has been a great experience having been able to share broad-ranging discussions of matter both academic and non- with a person with such multitude of interests. The academia needs a good bit of art.

This PhD would not have been possible without the help of students, research assistants and other co-authors who helped collect and analyse the data, and write up the original manuscripts for these publications. Thank you PhD candidate Ville Loukola for braving the autumnal weathers of the Seili island collecting the data for my research, as well as for content analysing it for social interactions. I could not have hoped for a more jovial and nice person to share those two isolated weeks with. Thank you also to M.A. Tuula Stenberg for help in developing the content-analysis scale and piloting its use for Study 2. Thank you also to M.A. Karoliina Peltola for spending the nights at the sleep laboratory collecting the validation data used in Study 4 as well as in writing the first versions of the draft. Here, I also wish to thank M.D., PhD Tarja Saaresranta without whom Study 4 would not been possible. The discussions and consideration that form the ossuary upon which the finalized articles test have been truly insightful and of great fun. Thank you for your valued collaboration!

I have had the privilege to carry out a vast portion of my research within a community of like-minded peers under the confines of the Centre for Cognitive Neuroscience and in the loftier surroundings of the division of psychology in general. The meetings, discussions and projects undertaken have been a spa-like experience for the brain and I wish to thank those involved either directly or indirectly in this work. Those of great importance for me and this PhD but not yet listed involve Dr Valdas Noreika (Queen Mary University of London) who provided me a chance to work on consciousness research already during my M.A., and who has continued to provide a true example of an embodied scholar with a humble and respectful attitude, Dr Valtteri Arstila (University of Helsinki) who´s wide-ranging interests always invoke new ideas and proposals, Gabriel Sjödin, who counts as among the most deep-thinking persons I know and a true mensch in attitude, PhD candidate Robert Chis-Ciure, an integrated information/Kant specialist with a mind the size of the Palace of Parliament, PhD candidate Heidi Haanila an expert in both consciousness of self as well as chess, Dr Mikko Hurme, our go-to engineer to distract with all the things one could build and code, Dr Mika Koivisto for providing always incisive and to- the-point commentary as well being an absolute force on the backline of a floorball court, professor emeritus Jukka Hyönä for being the backbone of the whole department for a vast majority of my PhD as well as positioning in a similar role on the aforementioned floorball team, to professor emeritus Heikki Hämäläinen, who I had the honour to have share the office next door and who always share curious insight into the broader context of Finnish Psychology. Thank you professor emeritus Pekka Niemi who in addition to being a role-model in scope of understanding and in attitude also made me feel at home at the department over 15 years ago with his raumaite welcoming air. There are too many to list: Sakari Kallio, Ari Kaukiainen, Riikka Korja, Susanna Salomäki, Niina Salminen-Vaparanta, Levente Móró, Milla Karvonen, Suvi Holm, Anna Kautto, Ida Luotonen, Timo Heikkilä, Simone Grassini, Otso Rantonen, Anne Salminen, Teemu Laine, Carina Saarela, Viktor Vorobyev, Myong Soo Kwon, Raymond Bertram, Faramosh Rashid Izullah, Oskari Lahtinen, Erika Johander, Hannele Räihä, Johanna Kaakinen, Ville Rajala, Sonja Kumlander, Susanne Uusitalo, Armi Hakanen, Paula Salo and Polaris Koi (for future endeavours!), and others. Special thanks to those who in actuality make all this academic work possible: Minna Varjonen for her infinite patience and immeasurable helpfulness, Maria Ek for keeping CCN on track, Vesa Rautio for keeping the PhD track running as smoothly as possible, and Nina Kramsu for helping with practical issues with undeserved kindness.

Finally, thank you students past and present, one could not hope for a better group of young colleagues to discuss, collaborate and have fun with. You are the heart of the university and have been essential in forming my teaching and thinking about psychology.

This research has been supported by the gracious financial aid from the Academy of Finland Human MIND project grant, that allowed me to begin my venture into research as part of a larger research consortium aiming to uncover the question of human consciousness. This has been appended by individual grants from the Emil Aaltonen foundation, the Turku University Foundation grant, as well as Graduate School of Psychology, and of The University of Turku Graduate Schools of Social and Behavioural Sciences and of Clinical Research that have provided opportunities for collaboration, cooperation and broadening of viewpoints. Thank you also for the Department of Psychology and Speech-Language Pathology for providing me with a position within the faculty during my PhD, as well as to the two projects for providing me further avenues while awaiting manuscript publication and finalizing this thesis: the narcissism research group from Helsinki University and Aalto University lead by professor Anssi Peräkylä, and the CLIMATE-NUDGE consortium at the University of Turku spearheaded by professor Paula Salo. These research groups are a true mixture of multidisciplinary ideas and hopefully keep my mind tolerably flexible even post-PhD.

Last but not least, family and friends. Irene. Thank you for supporting me through this, tolerating my non-traditional working hours and multitudes of interests and crazy ideas, understanding and discussing through such ideas when needed and helping me let go of work when required. I don't say it often enough, but none of this would be possible without you. Thank you also to my dear beloved Sofi, the absolute focal point who has centred me in a complete unprepared manner. You were not here when it started but I'm so glad you are here when it ends. My parents deserve a wider thanks of this PhD than they are likely to fathom. My father, Aarto, whose curious and creative spirit has taught me not to give up on impossible problems but to always ask the next question. You have taught me to find the joy in thinking and of tinkering just out of interest. My mother, Pirjo, who has taught me to laugh and enjoy whatever is there. Together you have always unconditionally supported me. You have tolerated my failures as well as my successes, exhibiting a completely unfounded optimism that I will find my way. Thank you. *Kiitos*. Kirsi, my older sister, who has been my role model from as long as I can remember. I have never had to question your support, for I know you to always be there. Thank you, friends: Antti, Thomas, Susa, Lauri, Paavo, Carlos, Markus, Henkka, Pasi, Linda, Teemu, Samuli, Yuki, Matthijs, Aart, Baran, Ferdinand, and others.

For better and for worse, it is now done. Thank you all for being there for it, and hope you'll stay there for the next act, whatever it may be. It is one thing to be privileged enough to stand on the shoulders of giants, but another completely to do so in such great company.

Turku, February 6th 2022
Jarno Tuominen

Table of Contents

List of Original Publications

This dissertation is based on the following original publications[1], which are referred to in the text by their Roman numerals:

Theoretical study

I Revonsuo, A., Tuominen, J., & Valli, K. (2016). Avatars in the Machine: Dreaming as a Simulation of Social Reality. In T. Metzinger & J. Windt (Ed.) *Open MIND: Philosophy and the Mind Sciences in the 21st Century.* Vol. 2. 1295–1322. Cambridge, MA: MIT Press.

Empirical studies

II Tuominen, J., Stenberg, T., Revonsuo, A., & Valli, K. (2019). Social contents in dreams: An empirical test of the social simulation theory. *Consciousness and Cognition, 69*, 133–145. https://doi.org/10.1016/j.concog.2019.01.017

III Tuominen, J., Olkoniemi, H., Revonsuo, A. & Valli, K (2021). No man is an island: Effects of social seclusion on dream content and REM sleep. *British Journal of Psychology.* https://doi.org/10.1111/bjop.12515

IV Tuominen, J., Peltola, K., Saaresranta, T. & Valli, K. (2019). Sleep Parameter Assessment Accuracy of a Consumer Home Sleep Monitoring Ballistocardiograph Beddit Sleep Tracker: A Validation Study. *Journal of Clinical Sleep Medicine, 15*(3), 483–487. http://dx.doi.org/10.5664/jcsm.7682

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1 Aims of the Study

There are but few questions that have so persistently gnawed at the human collective imagination as the question of *why do we dream*? Does dreaming serve any particular function or is it just a remnant of some other useful trait? Are dreams for making the self known or a means to hide it? For centuries dreams have occupied a liminal space somewhere between science and pseudoscience, humanities, philosophy and psychology, profound insight and utter bunk. Fears have been raised of either veering to theoretical fancy by relying on qualitative anecdotes on the one hand, or devaluing or reducing this curious phenomenon by viewing it from a scientific quantitative perspective on the other. As a result, the subject has been disregarded as jejune, not in the purview of the sciences proper. There have, however, been laudable forays into this uncharted territory, yet the crucial questions have remained unanswered. True, there are several uses dreams have been assigned to. For millennia they have allayed our fears of the future by using this ambiguous and suffusive material of to provide predictions of the future (Bulkeley, 2016). Dreams have been used to inform both movements in arts and practices of science, and they have been at the centre of various cultural practices. It is easy to understand and categorize such *uses* of dreams. Their *function*—if indeed it serves one—has been much harder to pin down. There have been various attempts that I will go through in detail in future sections. Such theories have provided great insights and illuminating findings. Throughout this thesis I will attempt to, however, show where these have in my view been lacking. They have either failed to consider the crucial social aspects of dream experiences, or they have done so in such a general fashion they do not fulfil the more rigorous criteria to constitute a scientific theory or an empirical research program.

Whereas the question of dreaming is indeed a vexing one it is overshadowed by the broader question of consciousness. The question of why we have internally generated experiences during sleep, is transposed to *why we have experiences at all*? Why and how does this gelatinous lump of tissue inside the skull provide such multifaceted experiences as the depth of lapis lazuli blue, the feeling of regret, or a childhood memory regained from a specific taste? Is experience just a random chance occurrence, the inevitable result of certain pattern of neurons firing that merely happens to feel like this? Why feel anything at all?

It is clear these two problems are intertwined. After all, dreaming is nothing if not an experience. It is merely a certain peculiar type of experience, one which is perceived in the absence of any external stimuli that usually furnishes our conscious percepts and experiences. Revonsuo (2006) has argued it to be just this feature of dreaming that makes them of specific interest for consciousness research. Dreaming can be considered a model system of consciousness, providing us with a glimpse of the machinery turned inwards, grinding its internally generated content to produce experiential states. Understanding how we consciously experience a world in the absence of—or in minimal contact with—external stimuli could gain insight into the very structure of consciousness. This is along a continuum to what Havelock Ellis may have had in mind when he visioned the quest for understanding dreams as "[f]or, rightly understood, dreams may furnish us with clues to the whole of life" (Ellis, 1911 pp. viii), or in more detailed fashion by Sully:

> "Instead of drawing its knowledge from without, noting its bearings in relation to the environment, the mind will now be given over to the play of internal imagination. The activity of fancy will, it is plain, be unrestricted by collision with external fact." (Sully, 1887, p.63)

Before we can use dreaming to tease apart the components that contribute to this state-independent structure of phenomenal consciousness, it is necessary to understand possible idiosyncrasies of dreaming. This research program implicitly necessitates an understanding of the biological functions of dreaming. Following this path of research allows for a new way of perceiving the twin problems of consciousness and dreaming. Is the function of consciousness the same as the function of dreaming? How do alterations in waking life affect our dream content? If dreaming is consciousness unbound, what types of content is it most acutely attuned to when not constricted by the external input?

In this dissertation I approach this problem by proposing a social function for why we dream. The aim is to, first, review previous research on the social dream contents and construct a hypothesis-generating theory to inform future research. Second, I aim to put this theory to use in the form of a research program and test some of the hypotheses in an empirical manner. Third, as progress in dream research is dependent on methodological development—one that arguably leaves much to be desired at its current state—I aim to develop and assess methods to aid in the practice of dream research. With these three aims I hope not only to propose a new way to consider dreams, but to nudge dream research towards a more unified, rigorous approach.

2 Conceptual Definitions

What do we mean when we talk about consciousness or dreams? To begin making sense of the phenomena we must first clearly define it. In this chapter I will briefly review the ways of conceptualizing consciousness, dreams and sleep. Metzinger (2013) puts the point clearly by defining dreams as a global phenomenally conscious state, and conversely, waking consciousness as “an online dream.”

2.1 Consciousness

Consciousness has been classified as one of the greatest unsolved scientific mysteries (Kennedy & Norman, 2005). Despite the centrality of consciousness—of subjective experience—in our everyday life, our understanding of how it should be conceptualized or measured, what function if any does it serve, or what is its biological or statistical basis remains elusive. Consciousness research has arguably reached (or *regained*) its still fledgling status as a respectable object of scientific study only in the early 1990´s, following the fall of behaviorism in psychology and the development of neuroscientific methodology. Here I will provide a short overview of the question of consciousness to the extent it relates to the question of dreaming.

2.1.1 Problem of consciousness

What is consciousness? A good working definition of consciousness should in the very least be able to include the whole spectrum of conscious states, from waking to dreaming and to other altered states, while simultaneously clearly exclude non-conscious processes or events (Velmans, 2009). In many other fields such simple delineation would seem a relatively easy task. Consciousness, however, poses a specific problem. At its very core, consciousness is a subjective experience, not necessarily objectively evident for external observers, as is apparent in the cases of either of locked-in syndrome (also referred to as pseudocoma) where patients are either nearly or completely unable to communicate with the external world despite remaining fully conscious (Laureys et al., 2005), or in anaesthesia awareness (Osterman & van der Kolk, 1998) where the patient regains consciousness during anaesthesia yet is unable to communicate their state to the environment. This inherent subjectivity has made the formulation of a concise definition difficult. Furthermore, it has led to problems in even beginning to build a research program for consciousness. As is evident in the previously mentioned examples of locked-in syndrome and anaesthesia awareness the definition of consciousness carries practical ethical implications for treatment of humans and other animals (Dennett, 1995)[2]. If consciousness is defined merely as responsiveness it may lead to ethically untenable behaviour towards people who remain consciously aware yet unresponsive (see e.g., Tavalaro & Tayson, 1997; Vigand & Vigand, 1999). Revonsuo (1995, 2000, 2006) has argued that dreaming should be treated as a model system for consciousness in which the "explanandum manifests itself in clear form" (Revonsuo, 2000, p. 73) and could thus be used to reveal the underlying theoretical principles for consciousness. Furthermore, as this view posits dreams as *pure consciousness* untainted in their isolation by external influence it maintains that "the ontology of dreams is the ontology of consciousness" (Revonsuo, 2000, p. 46). While Windt and Noreika (2011) have posed the conclusion of dreaming as a model system for consciousness currently problematic and thus premature, in the very least we should aim for an integrated and cohesive view of dreaming within the consciousness rubric. This *integration problem,* they argue, could more modestly be solved by contrastive analyses, where dream experiences are compared and contrasted with other conscious experiences in the wake, altered or pathological states (Windt & Noreika, 2011).

2.1.2 Form of consciousness

History of psychology is inhabited by various accounts to understand the form and structure of experience. Excluding certain pathological states of consciousness, such as coma or post-coma responsiveness (i.e., unresponsive wakefulness syndrome, formerly vegetative state) (Laureys et al., 2010), anaesthesia, or dreamless NREM sleep—and arguably some meditative states (Gamma & Metzinger, 2021; Thompson, 2014)—in a conscious state the brain always supports an experience of a spatially and temporally extended world. This presence of experiences is referred to as *phenomenal consciousness* (also *primary consciousness*, Sinclair, 1922), inhabited by a certain assemblage of contents resulting from the coordination between environment via sense input and an internally generated model within a specific brain-state that can support it (Block, 1995; Mansel, 1860; Revonsuo, 2006). This phenomenality is *experienced* by the organism; it feels like something

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[2] Or for that matter the ethical treatment of artificially generated moral agents, such as conscious AI (Bostrom & Yudkowsky, 2014; Wallach et al., 2011).

to be phenomenally conscious. The structure of this phenomenal world we find ourselves, both in waking and dreaming, commonly equates to a first-person experiencing subject for whom the spatiotemporal perceptual world presents itself. This phenomenal world has *qualia*, i.e., the experience has a quality for the subject, what Nagel (1974) called the “what-it’s-likeness” of being the organism.

Some of these phenomenal contents lie outside our immediate awareness, however. Block (1995, 2007) has defined the subset of these features we have conscious access to—i.e., those features we can consciously entertain—as *access consciousness*. Furthermore, we can bring a section of our phenomenal consciousness under reflection, and can thus report on it for ourselves and others—this is the task of *reflective consciousness* (Revonsuo, 2006) (also *secondary consciousness,* Sinclair, 1922). We can thus at least partially escape from the solipsism of private experience—to an extent we can know *what it is like* to be the other (Nagel, 1974), and can use this information to better coordinate our behaviour and share our internal states.[3]

How is the separate and varied sense input curated into a coherent unified whole of experience with phenomenal content? It is clear that the sense input from the present does not arrive simultaneously, as our sense organs are at varying distances from the brain, yet we combine, for example, the bodily sensation of hitting ones toe with the visual stimulus and the sound it creates—which also often arrives to both ears at slightly different times and which, again, are of different distances from the auditory areas of the brain—and create a simultaneous, flow of experience happening at once. What’s more, we can do this in a relatively reliable fashion, and are able to share this experience in an understandable fashion to others. This process of creating unity from various sub-experiences is called *binding* (Friston & Buzsáki, 2016; Revonsuo, 2006). In conclusion, our experience can be argued to be construed as a type of “virtual reality” (Revonsuo 1995, 2000, 2006) at the centre of which the subject, self-model or avatar is situated. This is more clearly the case in dreaming but arguably also in our waking life (Revonsuo, 1995, 2000, 2006; Tart, 1987).

2.1.3 Function of consciousness

The argument often repeated in various fields of inquiry is that *form follows function*. There are preliminary theoretical and modeling arguments that in the case of the brain, for example, the topological network structure and spatial embedding can be

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[3] The terms access and reflective consciousness are closely related. As Revonsuo (2009, p. 82) notes they both can be “regarded to talk about the same, selective-attention dependent, cognitive stage of consciousness, only emphasizing slightly different aspects of it.”

used to model functional networks (for a critical discussion see: Honey et al., 2010; Sarwar et al., 2021; Suárez et al., 2020).

As mentioned above the form of experience is commonly that of a spatiotemporal world, but what is its function? Why experience anything at all, as even the most complex behaviours could arguably be explained without reference to conscious experience (Chalmers, 1996). While most consciousness theories have aimed to explain the mechanism of how consciousness arises (for example, various higher order theories (Brown et al., 2019; Lau, 2007; Rosenthal, 2004), information integration theory (Tononi, 2004; Tononi et al., 2016) or global workspace theory (Baars, 1997, 2005; Dehaene et al., 2011), only few have ventured a biological function for consciousness (see e.g. Crick & Koch, 1998; Revonsuo, 2006). The argument for the biological function for consciousness range from the inference that anything so complex must have a biological function (Gray, 1971; Nichols & Grantham, 2000) to the fact that experiences have causal effects on behaviour (e.g. Gomes, 2005). Alternatively, several accounts consider consciousness not to carry any function, either by virtue of not existing at all (*eliminative materialism*, e.g.,Churchland, 1988)[4] or being epiphenomenal, i.e., without causal powers (e.g., Dennett, 1993; Huxley, 1874).

Psychological and neuroscientific research points to the fact that the task of the brain is not to veridically perceive and represent the external environment, but arguably to infer causes and predict consequences of actions in a manner that aids in species-specific goals (Buzsáki, 2019, p. 61). A good-enough model approximation would do, with biologically relevant features prioritized. In his theory of protoconsciousness, Hobson (2009) argues that this structure of the world is already prepared before birth in foetal REM sleep.

What are these models for? The currently in vogue predictive coding view makes use of models as an internal structure to understand mental life and behaviour. It argues that the main goal of the brain is to reduce uncertainty, and thus minimize surprise (or in the parlance of the Free Energy Principle of which the predictive coding view is an instantiation, to *reduce variational free energy*) (Friston, 2010, 2012). The way complex self-organizing systems best achieve this is by constructing a (statistical) model of themselves and the environment to allow for either more efficient anticipation of future events (i.e., model fit) or enact behaviours that reduce the dissimilarity between the expected and actual state (i.e., active inference).[5] In

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[4] Churchland has since rescinded the strict eliminative materialist view for a slightly more optimistic scientific approach (Churchland, 2002).

[5] The predictive coding view (used here loosely to also account for predictive processing, Bayesian brain and the free energy accounts) can be argued to sidestep the so-called

other words, the internal anticipatory model is constantly measured with the actual environment and only when there is a mismatch between the predicted and the actual input is a prediction error propagated in the brain, to be hierarchically processed until the mismatch disappears—either due to a more accurate state of the model or an action performed to conform the world to the expectation. From this characterization it is evident dreaming poses a challenge to predictive coding accounts, for in dreaming the internal generative models are not coordinated with external reality but left to their own devices (see Chapter 2.2.2.1). Furthermore, while predictive coding is a theory of brain function, it still is unclear why this internal-external choreography should be consciously experienced, i.e., why it should account for a theory of consciousness (Marvan & Havlík, 2021). It just seems that for some reason the hierarchical generative model is experienced (for predictive coding views on dreaming, see Chapter 2.2.1.1.3 and Tuominen & Valli, 2019).

In conclusion, while the form of conscious experience seems to be evidently that of a spatiotemporal world-model with the experiencing self in the centre, there is no consensus on what if any is the function of consciousness.

2.2 Dreams

Turning then to dreams as a specific subset of conscious experience, further conceptual issues arise, for the definition of dreaming proves a thornier subject one would at first hand expect. Historically the question of what dreams are and where do they come from dates back to at least the first written records in the *Epic of Gilgamesh* or the first extant dream reports from a historical person, the Sumerian King, Gudea, in 2200 BCE (Van de Castle, 1994, p. 48–49). Historically dreams have been mostly considered as something arising externally, as information and prophecies shared from the gods, ancestors or the netherworld (Van de Castle, 1994; Pick & Roper, 2004).

2.2.1 Form of dreams

Given this long history of dreaming as an object of interest it can be considered slightly surprising that as recently as the turn of the current millennia we still lacked a shared definition of dreaming (Hobson et al., 2000; Nielsen, 2000; Pagel et al., 2001). Fortunately, there has since been considerable progress on this topic. Philosophically, dreaming is nothing if not an experience—one that occurs during

representation wars, waged over whether the mind is representational and whether perception is for action (Clark, 2015; Constant et al., 2021; Williams, 2018).

sleep[6]—and thus an instance of phenomenal consciousness, where the contents are generated (mostly) from within by the sleeping brain (Revonsuo, 2006; Windt, 2010, 2013, 2015). Additionally, most dream researchers have converged to view dreaming as a sort of world simulation (Foulkes, 2014; Ramachandran, 1996; Revonsuo, 1995, 2006; Tart, 1987) with more specific differences in whether it is best described as a kind of virtual reality or an immersive spatiotemporal hallucination (Windt, 2015). The key aspect behind this type of view is that dreaming is structurally similar to the experienced world of waking consciousness. This has been noted already by Sully:

> “[Dream] …fashions its imaginary world on the model of the real. Thus, object group themselves in space, and act on one another comfortably to these perceived sense-relations; events succeed one another in time, and are often seen to be connected; men act from more or less intelligible motives, and so on. (Sully, 1887, p. 78)

or in a more poetic manner by Melinand as

> “confused reflections of real things” (Mélinand, 1898, p. 219).

There are, however, some differences between waking and dreaming experiences due to the changes in neurophysiological processes during sleep (Siclari et al., 2017; see also Ruby, 2020), and it is therefore appropriate to categorize dreams as an altered state of consciousness (Revonsuo et al., 2009). The apparent clarity the world-simulation concept provides is, however, deceptive, for dreams are varied on their characteristics according to the sleep stage or time of night. The fragmentary and static images that usually only contain one sensory percept are either considered as dreams as much as the more narrative immersive experiences by some (Flanagan, 2001) yet not by others (Hobson et al., 2000; Revonsuo, 2006; Windt et al., 2016).

2.2.1.1 Are dreams simulations?

Is it appropriate to consider dreams as simulations?[7] Simulation connotes an “imitative representation of the functioning of one system or process by means of

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[6] Even here, however, there is room from disagreement. Windt (2010) as well as Domhoff and Fox (2015) have proposed that dreaming can also occur outside of sleep, for example, during mind wandering.

[7] An influential alternative account for the simulation view has been proposed by Jonathan Ichikawa (2007, 2009, 2016). It considers dreams as imaginative activity during sleep and makes two claims that distinguish it from other dreams-as-imagination variations (i.e., Crowther, 2018; McGinn, 2004; O’Shaughnessy 2002; Sartre,

the functioning of another" (Merriam Webster, 2019). As such the use of the term seems appropriate: In dreams we internally generate a representation of the external world, and behave in it as it were real. Simulations can in general be considered to have two specific features. First, they simplify complex information. Simulations that mirror the complexity of the real world would be unfeasible and would not confer an added benefit as the map would be isomorphic to the territory. Simulations thus aim to extract the essential features of a given system. Therefore, they do not replicate the underlying mechanisms of the real world, they replicate its appearance. Given that we are only always aware of the external world via our sense organs, one could even more strongly follow the case made by Tart (1987) and Revonsuo (1995) that in fact our experience of the existing waking reality is already a type of simulation. We only have access to limited types of wavelengths, for example, and from this reduced input form a simulation of the world.[8] Second, simulations allow for useful repeated iterations of an event. This is the case in the more practical instances of flight simulators, war-gaming exercises or in mental preparation for a sports performance. Simulation provides a low-risk/high-reward platform for learning and attempting different solutions before performing the act in the real world. Other terms, such as *credible world analogue* (Foulkes, 1970), *imagination* (Ichikawa, 2007, 2009, 2016; McGinn, 2004; Sartre, 1940/2013), *virtual reality* (Revonsuo, 1995, 2000, 2006; Tart, 1990) or *spatiotemporal hallucination* (Windt, 2010, 2015) are descriptive, but lack the inherent intentionality in the term simulation: Simulations are *for* something, and thus the form itself is pregnant with the idea of function.

If the form of dreams were to be an evolutionarily based world simulation or virtual reality (Tart, 1985; Revonsuo 1995, 2000) this system should be relatively robust in its structure. Given that dreams in normative populations are primarily visual this evokes the question of blind people's dreams. What is the internally generated simulated reality of a person whose waking existence is somehow different from the general population? Indeed, the topic of dreams of the blind is both active and—in the case of congenitally blind individuals—controversial. Bértolo and

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1940/2013; Sosa, 2005, 2007; Sosa & Ichikawa, 2009; Soteriou, 2013, 2017; Thompson, 2014; Walton, 1990). First, dreams are a form of mental imagery, meaning that the experiences are similar in form when imagining them –for example, dreaming of the Parthenon would be similar to imagining it – in contrast to the simulation view where dreaming of the Parthenon would be similar to actually experiencing it. Second, Ichikawa (2009) argues our attitude toward the belief states in dreams is a propositional one, i.e., they are "imaginings." This means that a dream of Parthenon doesn't imply that one believes they are actually at Parthenon, whereas within the simulation accounts the dreamer takes the simulation as reality.

[8] See Revonsuo's *The Black Planet* thought experiment for a more thorough treatment of this argument (Revonsuo, 1995, 2006, p.117)

colleagues (2003) found dreams in congenitally blind people to be visual in nature, and them being able to represent their dreams in drawings.[9] Furthermore, there were no differences during dreaming between the congenitally blind and the sighted in the activity of brain regions responsible for visual perception (Bértolo et al., 2003). Similarly, Meaidi and colleagues (2014) found both congenitally and adventitiously blind participants to report visual dream content, albeit to a lesser degree than sighted participants (congenitally blind 21 ± 40%; adventitiously blind 49 ± 50%; sighted 99 ± 4%), and of shorter durations. To conclude, as individuals with no visual experiences can nevertheless experience dreams with visual imagery[10] the dreaming as a virtual reality would seem to not merely reflect waking experiences. In the congenitally blind the dream imagery seems to be mediated by cortical activation of areas responsible for visual representations in sighted participants (Fosse et al., 2003; da Silva, 2003). However, this doesn't mean the visual component to be necessary for dreaming, and studies have also reported the cessation of dreaming even in adventitiously blind people (see e.g., Charcot, 1883; Kerr, 1993; Solms, 2000; Windt, 2010)

Such findings of dreams to contain never-experienced contents are not limited to the blind. For example, studies on the dream contents of people with congenital or adventitious paraplegia have found their dreams to contain instances of walking, running, or swimming (Voss et al., 2011; Saurat, et al., 2011).

These would suggest a "hard-coded" ontogenetically updateable model where the main features (space, time, bodily self) would seem relatively robust against external disturbances. This would not be unlike the protoconsciousness model proposed by Hobson (2009, 2015) or, in the case of motor activity, the walking script proposed by Guertin (2009). This would also be in-line with a case study from the waking state, where a woman born without limbs reported phantom sensations of hands and feet, and while these did not elicit the usual sensorimotor cortex activity, they were nevertheless increased following sensorimotor cortex stimulation (Brugger et al., 2000). Alternatively, in the case of paraplegic walking dreams, these could be driven or maintained by the mirror neuron system, which allows us to mentally mimic other people's behaviours and, for example, learn motor or procedural skills by observation.

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[9] Visual dreams of blind people led Santiago Ramón y Cajal (1908) to formulate a neuropsychological theory of dreaming (cited in Ehrlich, 2017; López-Muñoz et al., 2008).

[10] However, this argument rests on the presupposition that we can distinguish visual from spatial cognition, an argument that in dreams (and even otherwise) is difficult to assess empirically. It could thus be argued that what we consider visual dream imagery is in fact spatial experiences that we interpret primarily as visual. For why we shouldn't describe blind people to actually "see" in dreams, see Kerr and Domhoff (2004).

2.2.2 Function of dreams

> “There is a tendency to be interested in the matter of dreams, in its aesthetic effects, much as we react towards ideas and events of real life in relation to our well-being. Of course this is the unscientific standpoint. The fact that a person dreams much or little is of more significance than what one dreams. A curve representing the variations from day to day in the amount of dreaming has scientific interest, while the hobgoblins that we saw are of interest to children.” (Nelson, 1888)

Dreams can be conceptualized either as possessing biological or invented functions, or as non-functional (Flanagan, 1995). Dreams have been proposed, for example, to increase psychological well-being (e.g., Hartmann 1996), simulate threatening events (Revonsuo, 2000), regulate emotions (e.g., Nielsen & Lara-Carrasco, 2007) or continue the content of waking thought (Domhoff, 1996). I will briefly review the most notable of such theories. While theories of dreaming differ in the question of function, there also exists another dividing line dependent on which component of dreams the theories consider. For example, while some theories scrutinize the contents of dreams, others concentrate on the neurophysiological correlates of dreaming, with some not distinguishing between these two (e.g., Malinowski & Horton, 2014; Revonsuo, 2000).

Alternative take would be that dream experiences are epiphenomenal and serve no direct function. This alternative opens two routes: Either dreams are random noise, or they are systematically related to other underlying neuropsychological processes that are functional in their own right. In this case a study of dreams is warranted, as it allows us to observe this function from an alternative angle (Bertini, 1973; Hartmann, 1973). Flanagan (1995, 2000) has proposed one the most detailed arguments for the epiphenomenal view of dreaming, where no uses—neither direct or indirect—are brought to bear. He concludes that we fail to remember dreams due to the fact they carry no use, but also they continue to existing as they also bear no considerable cost, that is , they do not detract from fitness (Flanagan, 2000). He summarizes his view:

> “Mother Nature caused us to dream because dreaming is what you get as a non-adaptive side effect of putting in place certain adaptations, especially ones involving selection for sleep and sleep-cycling.” (Flanagan, 2000, p.112)

Epiphenomenal accounts are by no means to be discarded, but considered as a valuable counterpoints to the functional theories. It is a strong claim that dreams or any other phenomenon has adaptive benefits and this is why such views should be formulated in enough detail to merit empirical evaluation. They are the null hypothesis every theory that makes functionalist claims should be considered against.

In dreams we experience counterfactual simulations, with unexpected events or norm-violations being present in 97% of dream reports, and nearly half of these include attempts to undo the event (McNamara et al., 2000, 2019). Ohaeri and Sunmola (1994) studied the patterns of dreams of 424 Nigerian students and workers and found 48.5% of participants to report dream experiences to later occur either sometimes or frequently in waking life as similar, and 12.9% as the opposite to how they were in the dream. Additionally, 29% of the respondents sometimes or frequently dreamt of past events, and 60.8% of what they were thinking about in current waking life (Ohaeri & Sunmola, 1994).

There is evidence that such preparatory simulations in dreams occur before salient future events. For example, performance in a competitive French medical school entry examination was improved in prospective students if they dreamt of the event the night before (Arnulf et al., 2014). Similarly, while not assessing the dream contents nor the temporal procession of the French study, general dream intensity score—which assesses the quantity, vividness, diffusion and altered episodes in dreams—was positively correlated with public examination results in Hong Kong (Yu, 2016). In another context, preparatory simulations have been observed in the “infant in peril” dreams of pregnant women, considered to exemplify simulatory preparation related to the babies’ future wellbeing (Nielsen & Paquette, 2007). However, explicit instances of prospection (i.e., mental time travel) were diminished in both non-rapid eye movement (NREM) and rapid eye movement (REM) sleep reports compared to wake reports (Speth et al., 2017). This would not seem to pose a problem for the preparatory simulation view, however, as strictly speaking the study assessed retrospectively reported memories of future states, i.e., whether the self was aware in the dream of engaging in mental time travel to the future, and not the experience of a likely future scenario experienced as immediate.

2.2.3 Theories of dream function

Dream research is in a state where there are a multitude of theories, yet no assessment on which of these are mutually exclusive, which propose opposing hypotheses, and which are aimed at different levels of explanation. Unfortunately, no thorough systematic review of the metatheoretical strengths or weaknesses of the various existing dream theories has been carried out. For a theory of dreaming to be truly comprehensive it must answer the twin questions of *how* and *why* dreams are constructed (Stickgold et al., 2001).[11] In other words, what is the constitutive mechanism for how memory sources for dream contents are selected and modified on the neurophysiological level and how they are combined to form the dream experience, and what—if any—is the use and value of dreams in an evolutionary, behavioural and/or psychological sense. Furthermore, a theory of dreaming should clearly consider the way dreaming differs from sleep, as well as to consider the distinct aspects of dreaming compared to other experiential states. Such a theory should also be simple yet covering, it should be progressive, i.e., it should generate novel testable hypotheses, and it should be empirically testable (Revonsuo et al., 2016b).

The scope of this thesis cannot do justice to the cornucopia of dream theories, and thus a brief overview of the most common as well as the most relevant for the topic at hand will be discussed. I will, first, present theories that posit no biological function for dream contents, followed by a listing of theories that see dreams as functional. In Chapter 2.2.4. I focus specifically on existing theories and findings that posit a social function for dreams.

2.2.3.1 Non-functional dream theories

2.2.3.1.1 *Continuity hypothesis*

Continuity Hypothesis (CH) (Bell & Hall, 1971; Hall & Nordby 1972) is in actuality an umbrella term, containing various theoretical developments that all share the overall core argument that dreams in some form or another are causally continuous with waking experiences. Overall, they can be classified in the group of theories that posit a psychological function for dreams and remain silent on the possible biological function. The specific formulation differs as some theoreticians propose the actual waking events to affect dream content (Foulkes, 1985; Schredl & Hofmann, 2003), while others place weight on the cognitive content of waking concerns and interests (Domhoff, 2017). Originally, Hall and Nordby stated the continuity hypothesis as:

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[11] This claim already presupposes some metaphysical positions. Namely, that a) dreams are constructed by our brain and that b) we have access to information about relevant neural activity. These assumptions are widely shared and uncontroversial and thus alternative views are not considered within the scope of this thesis. Indeed, while the rejection of the first premise would likely lead to a supernatural view where dreams are ‘given’ by an external agent the rejection of the latter can be more scientifically argued. In this instance the question quickly becomes on the granularity and level of observation and thus is transformed into a technical question: Are our measurement devices appropriate.

> "The wishes and fears that determine our actions and thoughts in everyday life also determine what we will dream about" (Hall & Nordby, 1972, p. 104)

There is an ongoing debate on what content exactly should be continuous (see e.g., Domhoff, 2017, 2019; Mageo, 2019), how continuity should be assessed and whether the varying forms of continuity hypothesis do in fact share anything more than a family resemblance. In practice this makes the empirical evaluation of continuity difficult, as the common conclusion in several studies that a finding supports the continuity hypothesis is often not specific and could just enough be explained by the autobiographical memory sources of dreams, for example. The problem is thus in the vagueness of the term *continuity*, which is open for interpretation. Therefore, it helps clarify the situation if we were to distinguish between various forms of continuity and assess each of the subgroups at their own merits.

The Cognitive Continuity Hypothesis (CCH) argues that only those waking concerns that are of personal significance to the dreamer are reflected in dream content (Domhoff, 2011). Overall, while CCH has intuitive merit and has some empirical corroborating evidence behind it, the theory is vague to derive truly risky hypotheses from. CCH is, for example, liable to verge on circularity as the intensity of individual concern is revealed by the "…frequency with which a character, type of social interaction, or activity appears in a series of dreams…" (Domhoff, 2017, p. 15), while past dream report findings are then taken to prove the original hypothesis that: "…the most important influence on the frequency of specific types of content in dreams [is] the intensity of personal concerns." (Domhoff, 2017, p. 15).

CCH has taken steps to move beyond mere compiling of previous findings. There are some studies where dream contents are retroactively mapped unto waking concerns, as well as analysis of longitudinal dream report series for patterns within single individuals from their personality and life history (Bell & Hall, 2011; Domhoff, 2010; Domhoff & Schneider, 2008). Unfortunately, this method also has a danger of falling into overfitting or confirmation bias. It should be noted, however, that Domhoff has addressed these theoretical concerns, and stated that CCH is not a theory of dream contents at all, but a replicated empirical discovery (Domhoff, 2017). These findings have then been refined and incorporated to the broader *Cognitive Theory of Dreams* as embodied simulations that dramatize conceptions and personal concerns (Domhoff, 1996, pp. 209-212; Domhoff, 2017).[12]

The Incorporation Continuity Hypothesis (ICH) has appeared in several forms, but has been more clearly defined by Schredl and Hofmann (2003) as non-functional

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[12] For a thorough review, see Domhoff (2010, 2017).

continuation of wake processing. Dream contents thus directly and non-selectively reflect wake experiences and events (Domhoff, 2017; Schredl, 2003; Schredl & Hofmann, 2003).[13] However, despite of the argued commonality of incorporated waking events, only approximately half of dreams contain even the slightest dreamer-identified day residue (Botman & Crovitz, 1990; Domhoff, 2017). The methodological problems of studies that have attempted to correspond dream reports to daily reports from the same participants for immediate or delayed residual content (e.g.,Blagrove et al., 2011; Henley-Einion & Blagrove, 2014; Marquardt et al., 1996; Nielsen et al., 2004), are liable to similar biases as the CCH studies.

2.2.3.1.2 *Activation-synthesis and AIM models of dreaming*

In 1977 Hobson and McCarley proposed a novel Activation-synthesis model to explain dreaming, with the specific aim of joining the recent recoveries of reticular activation system (Moruzzi & Magoun, 1949), and the REM off-cells in the locus coeruleus and raphe nuclei that allow the brain to regulate REM sleep (Hobson et al., 1983). Later, the Activation-synthesis model was updated and termed the AIM model (Hobson et al., 2000). The abbreviation comes from the components of activation, information source, and modulation, respectively. These three components are active in a three-dimensional state space model. In short, the theory states dreaming to be likely when the brain is activated in REM sleep, muscle atonia is present and sense input is inhibited, and when the chemistry of the brain is altered toward high cholinergic and low monoaminergic modulation. AIM is often stated to account for the resulting dream contents as mere chaos or noise, yet Hobson (2015) has vigorously argued against such reduction. He states that the structure of the model should emphasize certain features, such as bizarreness, emotions, intense motor and sense perceptions as well as post-dream amnesia (Hobson, 2015, p. 198). Similarly, Hobson answers the critique of only accounting for REM dreams and thus leaving out a significant portion of our dream experiences, that he never in fact claimed AIM dreams to be exclusively of REM, but them to account for the most luminated example of this phenomenon.

2.2.3.1.3 *Predictive coding*

In recent years the predictive coding framework has been used to explain various phenomena in the brain and mind sciences. It is based on the free energy principle

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[13] Schredl (2003) proposes a more detailed mathematical model which could lend predictive power to the theory. However, the applicability of the model in enough detail remains uncertain.

(FEP) as reviewed in chapter 2.1.3, which states that every self-organised system aims to remain in a non-equilibrium steady state by minimizing the difference between the internal and external states of the organism.[14] In other terms the task of the organism is to minimize free energy and avoid surprise by attempting to model the environment as accurately as possible. When this model fails to account for the events in the external environment, a prediction error signal is processed up the hierarchically organized levels of brain organization with the aim of updating the model to match the external situation.

This model has been proposed also to account for dreaming. Hobson and colleagues (Hobson et al., 2014; Hobson & Friston, 2012, 2014; see also Windt, 2018) have proposed dreams to be epiphenomenal in that the biological function lies in the overall mechanism of prediction error minimization and dreams are a by-product of this system. During the day the model is considered to maximize the fit between external and internal realities and as such is liable to overfit the model. During sleep, when sense input is offline and the environment does not create prediction errors to disturb the parameter optimization process, the complexity of the model is reduced to avoid the model being too fixed to react to new circumstances in an optimal manner. However, it should be noted that FEP is a principle, and as such arguably unfalsifiable (Colombo & Wright, 2021), which poses problems for the scientific merits for not only FEP but the derivative theories. However, FEP has recently been suggested to serve as a regulatory principle for derivative process theories, and as such the unfalsifiability of FEP should be left aside as falsifiability does not concern *a priori* (Hohwy, 2020). For dreaming, however, the theory should be able to generate some testable predictions. Currently it seems that most findings that support PC views of dreaming also support the world simulation views of dreaming in general.

2.2.3.1.4 *Elaborate encoding theory*

One instantiation of that can be considered to retain both Hobson and McCarley´s (1977) earlier activation-synthesis theory and to provide a way to explain for the practice of dreams for interpretative purposes is the elaborate encoding theory, proposed by Llewellyn (2013, 2016). In short it maintains that emotionally salient but remote associations are elaborated by REM sleep dreams. Such conjoining

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[14] A useful term for the organism is Markov blanket, a statistical concept that denotes a subset of variables which contain all the information about a given system required to make inferences about it. A minimal subset which cannot lose any variable without removing information is called a Markov Boundary. FEP considers systems that have a Markov blanket.

allows for restructuring and consolidation of memories, and the further the associations are elaborated—i.e., the longer into the sleep the process is—the more the associative memory is enhanced and enriched leading to the hyperassociative nature of dreams already remarked on by Freud (1900/1953) and preceded by a host of various theories of dream interpretation (for a comparative history of dreams in various cultures, see Bulkeley, 2008). While this theory is notably difficult to test in practice (Hobson, 2015) it has been proposed to gain indirect support from the findings of Spitzer and colleagues (1991) that semantically primed remote-associations are more rapidly recognized when the task is performed immediately following REM sleep. Notably, one could argue the elaborative encoding view to easily sit with the theories of dreaming that propose creativity or problem solving as a psychological function of dreaming. As with several of the other theoretical accounts, this theory would gain from added specificity and by derivation of testable predictions.

2.2.3.1.5 *Wish fulfilment*

Freud's is arguably the most known dream theory.[15] Given that Freud revisited and reiterated his theory on the function of dreams for over 40 years, the specific theory may be difficult to pin down. Due to the voluminosity of his writings[16] most take *The Interpretation of Dreams* (1900/1953) to stand as the definitive account for a Freudian dream theory. Freud in this and in many iterations of his view on dreaming emphasises the wish fulfilment function of dreaming. He sees dreams in essence to be central in the individual's aim of mastery of the internal and external. Later, as a response to critics and other developments Freud revised his view. In order to accommodate dreams that are negative or consider traumatic events Freud adjusted his theory of the pleasure principle In *Beyond the Pleasure Principle* he writes:

> "…it is impossible to classify as wish-fulfilments the dreams we have been discussing which occur in traumatic neuroses, or the dreams during psychoanalyses which bring to memory the psychical traumas of childhood." (Freud, 1920/1955, p. 32).

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[15] This is understandable considering the role Freud had in bringing the overall notion of unconscious mental life into public and scientific life. It should be noted, that the term and concept of the "unconscious" itself is not original to Freud, but preceded him by several other authors, possibly starting from Herbart's theory of *limen* and the threshold of consciousness in the mid 19th century (Kim, 2015).

[16] The Standard Edition of the Complete Psychological Works of Sigmund Freud contains 24 volumes and approximately 8000 pages.

He sees here an additional, more primary function for dreams: Such negatively valenced dreams are necessary to endure before normal dream generation can continue, as they attempt to retroactively regain mastery of the unwanted stimulus (Freud, 1920/1955, p. 22). Furthermore, for example dreams of capture presenting in prisoners of war before being actually captured can in Freudian terms be categorized as warning dreams, triggered by the same mechanism that generates anxiety signals in the waking life, both under the service of self-preservation (Freud, 1940/1966).

There is an extensive debate and discussion on the value and use of Freudian dream theory that is well beyond the scope to be reviewed here. Most famously, Popper (1963) has criticized the theory—and specifically its clinical use—as unfalsifiable. The revisions to the theory mentioned above were specifically to account for dreams that seemed fallacious to account for as wish fulfilment. Furthermore, McCarley and Hobson (1977) argued the role of the brainstem instead of the cortex in the generation of dreams to dismiss the idea of dreams as wish fulfilment. Wishes were higher order processes, and as the brain section related to such operations was inessential for dreams the theory could be dismissed (McCarley & Hobson, 1977, p. 1219). This discussion has been ongoing ever since, especially since Solms' (1997) findings that the brainstem is necessary but not sufficient for dreaming (see also Solms, 2020).

2.2.3.2 Functional Dream Theories

2.2.3.2.1 *Threat simulation theory*

The Threat simulation theory considers dreams to have a biological function of simulating threatening events (Revonsuo, 2000). It posits dreams to having increased survival as a consequence of simulating threatening events and scenarios in the safety of sleep (Revonsuo, 2000; Valli & Revonsuo, 2009). Dreams provide a risk-free training ground, a virtual world, in which the dreamer can practise the perception and recognition of threatening events, and the behavioural strategies of threat avoidance. This practise in the dreams rehearses or strengthens the respective underlying neurocognitive mechanisms. This in turn increases their chance of survival and thus carries evolutionary benefits. The Threat simulation theory's strength lies in its grounding on a specific theoretical view on consciousness (*Biological Realism*; Revonsuo, 2006) and the way its formulation generates specific empirical hypotheses. In the original development six propositions were staked.

First, dreams are a selective simulation of the perceptual world, i.e., dreams are an opaque world simulation organized similarly to the perceptual waking consciousness, and it is biased toward specific types of experiences (emotional, social) while omitting others (e.g., reading, writing). Second, dream contents are selectively biased toward threatening contents and negative situations that afflict the dreamer or his or her close others. Threat generation is considered the original function of dream consciousness. Third, this threat generation system is activated by real threats in the environment. Therefore, the intensity of the threat simulations should be in relation to the experienced personal threat and should not contain cultural variation (given there are no threat-simulation-related genetic differences between cultures). Fourth, to carry out the proposed function dreams should be realistic threat simulations both behaviourally and perceptually. Consequently, in cases where muscular atonia observed in REM sleep would be removed, we should observe motor actions isomorphic to the dream contents. Fifth, these simulations should have a real-life effect, i.e., they should be considered as mental training that increases performance. Finally, sixth, the Threat simulation theory claims that our environment of evolutionary adaptedness (EEA) was rife with threatening events and imposed selection pressures that favoured the survival of the trait (Revonsuo, 2000; Valli & Revonsuo, 2009).

Currently, the argument for a dream threat simulation system has gained support from empirical studies. For example, dreams do seem to be biased for simulating negative emotional contents, events and themes more than we encounter in corresponding waking life (Hall & Van de Castle, 1966; Valli & Revonsuo, 2009). Furthermore, threatening surroundings in the waking state seem to increase the simulation of threatening events in dreams (Valli & Revonsuo, 2009).[17]

Despite the empirical and theoretical merits of the Threat simulation theory it only covers a sub-section of dreams. While the results differ relatively widely due to differences in methodology it is estimated 8.5–20% of dreams contain realistic or life-threatening threats (Malcolm-Smith et al., 2004, 2008), and 38–77% contain threatening events overall (see Revonsuo & Valli, 2000; Valli & Revonsuo, 2009). However, this leaves at best a fifth and at worst—in the case of only accounting for lethal threats—nine tenths of dreams unaccounted for and therefore arguably is an unlikely candidate for the sole function of dreams. It fails to explain, for example,

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[17] While the cohesiveness of the theory and its explanatory depth are arguably unique, similar arguments had been tentatively proposed previously. For example, Carl Sagan (Sagan, 1977) or V. J. Ramachandran (1996) have in their writings at least nodded toward such an evolutionary dream function. Sagan argues that during dreaming, in the safety of sleep, the so-called R complex reigns and can demonstrate our "reptilian" brain processes such as sex or violence that would have us quickly killed in the real world. Ramachandran (1996) points toward a more psychoanalytically oriented view where the dreaming brain can sidestep the waking defense mechanisms and attempt to incorporate the emotionally laden events into "the main script", or alternatively to re-repress it.

the non-threatening, neutral, positive or social dream contents (e.g., Bulkeley, 2004; Humphrey, 2000). It is precisely this criticism of the limited scope of the Threat simulation theory that has motivated the theory forwarded in this thesis, aiming to propose for an alternative simulated functional content to bridge this gap.

2.2.3.2.2 *NEXTUP*

The most recent addition to the theoretical fold to account for dreaming is the NEXTUP model by Zadra and Stickgold (2021). The acronym accounts for *Network Exploration to Understand Possibilities*, and it proposes a prospective function for dreaming of visiting weakly connected memories to entertain new possibilities. Specifically, via sleep-dependent memory processing dreams select weakly associated memory traces for the construction of imagined scenarios. The theory posits dreams monitor the experienced associations from immediate nondeclarative and semantic memory sources from the preceding day as well as more distant memory traces for whether or not they elicit an emotional response. If such feelings are evoked these are marked and the associational connections between the memories are strengthened for use in wakefulness. These strengthened weak emotionally tagged associations provide novel or creative insights that are of use in the wake state. NEXTUP makes the argument that REM sleep dreams are emphatically not experienced as episodic memories (these occur in N2) or simulations but based on the semantic associations of the experienced episodes. This accounts for the hyperassociative and metaphorical quality of dreams.

Furthermore, it is proposed that NEXTUP dream function varies between sleep stages. Sleep onset is considered to tag current concerns for further processing with the aid of the brains Default Mode Network (DMN) activity, akin to a first round of reviews. In REM sleep dreams use the world simulation to generalize from the selected memory sources an integrated understanding.

NEXTUP proposes an evolutionary function for dreaming of the brain to self-generate new information by running imagined simulations while monitoring both its own response and the responses' effect on the experience. The result is that the brain can identify likely useful information from weak associations not available in the waking, and thus increase the use-value of the represented memories. While a possible explanation for why we dream, this account is still novel and as such rudimentary. For example, it still lacks a more thorough evolutionary description or assessment for why, for example, would the weak association linkage increase fitness? Furthermore, it still lacks a clear research program that provides novel empirical hypotheses. Nevertheless, it provides an addition that considers the interplay between various memory systems in dreams, and as such is likely to spark interesting discussions.

2.2.3.2.3 *Dreaming as play*

Finally, Bulkeley (1993, 2019) and Humphrey (2000) have proposed dreaming as imaginative play in sleep. Bulkeley and Humphrey both argue for dreaming to share key behavioral components of waking life mammalian play. These include practice and rehearsal, enabling possibilities beyond typical waking experiences, while incorporating topics and concerns from social life. The evolutionary path for dreaming has thus been for play behaviour to having also been extended to our sleep. They see the evolutionary fitness benefit of dreaming to be the same as that of play, and thus liable to having been selected for. According to Bulkeley (2019), those species that play the most also have the most REM sleep, and by analogue the most dreaming. Additionally, the bizarre features—instances where dreams are discontinuous, surprising, or weird—are similar to the reality distortions evidenced during imaginative play. When the person is in a state of crisis, for example, experiencing post-traumatic symptoms, both REM sleep and play behaviour are found to contain more repetitive fixed patterns, with markedly diminished novelty or curiosity (Bulkeley, 2019).

While the dreaming as play analogue is an interesting view, and undeniably they share similar features (for example, construction of imaginary simulations of salient situations), it is difficult to consider the prospective value of this theory beyond description based on similarity. What would the hypotheses for empirical dream research from this view contain, and how would they differ from those posited by other theories (e.g., Threat simulation theory, Imagined interaction theory (see Chapter 2.2.3.3.4), NEXTUP)? Furthermore, an assessment on the similarities and dissimilarities between dreaming and play would provide a more specific understanding beyond similarity.

2.2.3.3 Theories of social dream function

In addition to the previously mentioned theories that have either not considered the content of dreams as functional at all, or have proposed primarily a non-social functional content, there are also several theories and hypotheses that have considered dreams from explicitly a social viewpoint. The overall idea of dreaming as social simulation to carry an evolutionary function has been proposed by several authors (e.g., Brereton, 2000; Franklin & Zyphur, 2015; Kahn & Hobson, 2005; McNamara, 1996).

2.2.3.3.1 *Theory of Mind and Mentalization as a function of dreams*

One proposed function of dreams is the development and practice of theory-of-mind and mentalizing skills. These two terms are largely overlapping and are in the literature often used interchangeably. However, they denote slightly different processes. Theory of Mind (ToM) is the general capacity to attribute mental states to others. Accurate ToM inferences, then, function as a basis for interpreting and predicting the actions of others. A long-standing debate as to whether ToM is based on a theoretical (theory-theory, Gopnik, 2003, 2011) or a simulation-based (simulation theory, Gallese & Goldman, 1998) inference has been undergoing for past two decades, yet no clear conclusion has been reached. The term ´mentalization´ partly rests on ToM, yet is more specifically considered an imaginative mental activity to derive others' intentional and emotional mental states, goals and desires (Frith & Frith, 2005). As such both skills are considered essential for our social functioning, in- and out-group relations, and cooperative collaboration.

The evolutionary argument for the development of ToM or mentalizing skills, in short, states that the more accurate the beliefs about the intentions and contents of others' minds, the better the individuals' chances of survival (McKay & Dennett, 2009). It should be noted, that the uses of mentalizing are not limited to prosocial or group cohesive uses, but also allow the individual to manipulate and deceive other group members (Humphrey, 1976), and themselves—arguably partly to better in turn deceive others and to avoid negative reciprocal consequences of being found out (Trivers, 2011). Regardless of the specific mechanism, it has been argued that mentalizing should be considered to lie at the very foundation of human society (e.g., Tomasello, 2006, but see c.f. Hirschfeld, 2013), as it allows for cumulative cultural learning and transmission of abstract information. The pervasiveness of mentalization is evident in our proneness to anthropomorphize; to attribute intentionality and mental states to both animate and inanimate entities (e.g., (Urquiza-Haas & Kotrschal, 2015). This is what the philosopher Daniel Dennett (1987) has termed the "intentional stance".

Given the propensity to consider the minds of others in the waking state the question then arises: do we dream of other minds? The peculiarity of this question is best summarized by Schopenhauer

> ”Nothing provides so vivid an illustration of this identity as a *dream*. For in a dream other people appear to be totally distinct from us, and to possess the most perfect objectivity, and a nature which is quite different from ours, and which often puzzles, surprises, astonishes, or terrifies us; and yet it is all our own self." (Schopenhauer, 1896/2005, pp. 73)

In short, if all the dream characters we experience are the product of our own mind why would there need to be any mindreading in the first place? The dream characters' minds and intentions should be fully transparent and, thus, there would be no need for trying to understand them. This question is illustrated in a dream described by the philosopher Samuel Johnson where he had lost a contest of wits to his dream-opponent:

> "…for had not my judgment failed me, I should have seen, that the wit of this supposed antagonist, by whose superiority I felt myself depressed, was as much furnished by me, as that which I thought I had been uttering in my own character". (Boswell, 1818, pp. 12–13).

Further, Calkins (1893, p. 335) notes an instance of this same phenomenon in a dream of Van Goens failing in a recitation, only to have the other dream character answer correctly. These historical examples illustrate the opacity of other minds even in our dreams. We constantly grasp at the intentions and mental contents of others in an attempt to coordinate, understand and cooperate.

Brereton (2000) in his *Social mapping hypothesis* has proposed the simulation of mind-reading as well as more general other perception as a function of dreaming. This theory explicitly contains an evolutionary view and considers dreaming as a rehearsal ground for emotional and perceptual abilities that in general relate to mapping of the self-body image into a salient social world. Lastly this view is supported by the view that in groups known to exhibit problems in spontaneous theory of mind inferences, such as people in the autism spectrum, the amount of social dream contents seems to be diminished (Senju et al., 2009).

2.2.3.3.2 *Empathy theory of dreaming*

Recently, Blagrove and colleagues (2020, 2021) devised the *Empathy theory* of dreaming. They propose dreams to have a socially beneficial empathy function post-sleep when dreamers share their dream with others. Nearly all (97.9%) participants in an undergraduate survey report telling at least one of their dreams to others (Vann & Alperstein, 2010), while on the individual dream level approximately 14.5% are shared with close others (Schredl & Schawinski, 2010). Whereas most theories argue for the dream function to reside in the dream generation and production phase, the Empathy theory of dreaming places the onus on what we do with dreams after they have been experienced. As such it is not mutually exclusive with theories about dream content, but proposes possible evolutionary backstories on the likely survival of such a trait, while leaving open the option that dream sharing is a spandrel, co-opted for a beneficial use (Blagrove et al., 2019). There are likely fitness benefits from storytelling for the individual and for the cohesion of the group. However, it would seem that merely fictional confabulated narratives would suffice for these functions, with no need to truly experience anything during sleep. Indeed, the authors propose that this social sharing of private experiences and narratives could be the function of consciousness in general, not merely of dreams in particular.

While the theory does an amiable job in reviewing the benefits and uses of dream sharing and corresponds to the theory of fiction as social simulation[18]—it also at this stage suffers from some limitations. First, the evolutionary description rests on a relatively speculative foundation. While they did find listening to other persons' dreams to increase empathy toward the sharer an opposite non-significant trend was found to hold for the dream narrators' empathy toward the listener. Second, as the authors note, the first tests of this theory did not yet control for possible confounds, such as attachment styles, motivation for dream sharing or whom the dream was shared with. It may be that from an evolutionary view the Empathy Theory of dreaming may best reside as part of the more general self-disclosure or narrative sharing functions, and not as a function of dream per se. In any case, it allows for a very interesting view on dreams and provides testable hypotheses. Additionally, it provides a way for the social contents of dreams to have an effect on the external waking world.

2.2.3.3.3 *Social bonding and attachment theories*

One of the earliest dream theories for an explicitly social function was proposed by McNamara (1996, see also Zborowski & McNamara, 1998). He maintains REM sleep promotes social bonding and facilitates long-term attachment patterns by reactivating the attachment system during sleep. Similarly, Nielsen and Germain (2000) have supported a view of attachment-themed or other interpersonal dream simulations as maintaining their significance. One possible mechanism would be the long-term memory consolidation of emotional memories in REM sleep. Dreaming is proposed to affect waking behaviours through activation and processing of persistent attachment related themes. On the dream level this is marked by bonding themed dreams, especially in individuals whose attachment needs are not met. For example, insecurely attached participants were found to dream more often and experience more intense imagery. In a pilot study McNamara and colleagues (2014) assessed the change in intimacy during dreams in a single night in relation to attachment type. They found intimacy themes to increase over the course of the night, but the rate of increase being lower for the avoidant group than either for the secure or preoccupied groups. Selterman and colleagues (2012) analysed the dreams of 61 undergraduates in a committed relationship for secure base script elements. They found attachment security to correlate with the number of dreams about

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[18] For a social simulation function for reading fiction, see Mar and Oatley (2008) and Oatley (2016).

romantic partners and the likelihood of dreams containing attachment-related secure base scripts. Interactions in REM sleep dreams increased as the time asleep progressed, but at a lower rate in avoidantly attached people. Insecurely attached people evidenced more conflict in romantic relationships represented in dreams (Selterman & Drigotas, 2009). On the same vein, Selterman and colleagues (2014) found dreams to have direct effects on the subsequent waking attachment experiences, with a correlation between the presence of romantic partners in dreams and the experienced closeness and amount of interaction the following day. Overall, insecure attachment seems to be related to reduced dream recall and reduced REM latency, leading McNamara and colleagues (2001) to propose maintenance, construction, and adjustment functions for internal working models. This is proposed to specifically relate to REM sleep due to it being associated with consolidation of emotional memories, compared to the declarative and procedural memories being consolidated in NREM sleep (Stickgold, 2013; McNamara, 2014; c.f., Fogel et al., 2007).

Given that our experience of self and others is mediated or moderated by our attachment-related internal working models it comes as little surprise that our interpersonal dream world is correlated with self-other experiences in the waking. For example, Mikulincer et al. (2011) found insecure attachment to be related to negative self-concepts in dreams, and McNamara and colleagues (2011) similarly found increased self-denigration, as well as an increase of aggression themed content in anxiously attached peoples' dream reports. Mikulincer and colleagues (2009) found attachment-related anxiety and avoidance correlated with less support seeking, whereas in another study attachment anxiety and avoidance was correlated with less within-dream awareness and reflection compared to secure attachment (Mikulincer et al., 2020). Finally, Hill and colleagues (2014) investigated whether psychodynamic psychotherapists and their patients dream of each other during treatment. Interestingly, while the therapists often dreamt of their patients, only two of the most highly anxious and abandonment fearful patients recorded having dreamt of their therapist.

In conclusion it seems that our interpersonal world in dreams, similarly to our waking is related to how we relate to close others. Those with whom we form attachment relationships seem to occupy a vast amount of our dream experiences. Whether or not attachment view provides a *comprehensive* account for why we dream is, however, debatable. Nevertheless any account of dreaming should be able to contain these findings under its explanatory cover.

2.2.3.3.4 *The imagined interaction theory*

The imagined interaction theory (II) (Eldredge et al., 2016) considers imagined social interactions in daydreams as its starting point and expands the idea to also cover night dreams. They define the mechanism to consist of cognitive scripts—non-conscious general rules of thumb (Honeycutt & Bryan 2011)—which are organized into imagined interactions that aim to prepare the individual for future events and actions. The theory differentiates from fantasy by only including interactions that have a high likelihood of actualizing in the life of the individual. Overall IIs are characterized by eight attributes. These are: the *frequency* of IIs; whether II takes place before or after (*pro-* or *retroactivity)* the actual interaction; *discrepancy*, i.e., the similarity between the actual and the imagined interaction; *self-dominance* which tracks the most active communicator in the II; *variety* of interaction topics and partners; *valence* of the emotional content of II; and, *specificity* or the level of detail of II. Additionally, IIs are considered to carry the six functions of *relational maintenance*, *conflict-linkage*, *rehearsal*, *self-understanding*, *catharsis* and *compensation*. This theory has been tested in night dreams only in one study, which did find nearly 72% of dreams to carry some form of II function, primarily related to self-understanding (41.6%) or relational maintenance (30.1%) (Eldredge et al., 2016). It provides an interesting addition to the dream theory fold, with its roots in social interactionism and script theory.

2.2.4 A theoretical note

After reviewing the existing theories proposed to account for dreaming, a more general theoretical note is in order. Theories of dreaming appear to have a curious feature of expansion: often they originally concentrate on one more or less strictly defined function or feature, only to iteratively expand, distend and spawn offshoots. These include the continuously revised and expanded views of Freud, the move of Hobson from the activation-synthesis theory (Hobson & McCarley, 1977) to a predictive processing theory (Hobson & Friston, 2012) by route of protoconsciousness (Hobson, 2009), and to a smaller extent the expansion underlying this thesis from threat simulation to the social simulation function of dreaming (Revonsuo, 2000; Valli et al., 2009). This dynamic seems to take place at the level of auxiliary hypotheses, and a more positive view is uncovered by assessing the way the broad drive has simultaneously been toward a shared conception at the root of the current theories (see Chapter 2.2.1). Thus, it seems that the current degenerative state is partially illusory; a result of various existing theories converging on a core background assumption. This resulting shared framework in turn allows for more rigorous testing between various theories at various levels of description.

2.3 Sleep

Given the problems of defining consciousness and dreams, sleep would seem to be far less ambiguous a concept. This, however, is not the case. Sleep is an exceedingly complex phenomenon, and can be approached either as a brain state, a process or a behaviour that takes place in different spatiotemporal scales (Vyazovskiy & Delogu, 2014; Vyazovskiy & Harris, 2013). Furthermore, as with consciousness in general, sleep has a certain form as distinct states of the brain, and has also been proposed to carry certain functions.

Two features of sleep warrant its treatment here. First, sleep is the background condition for dreaming. Second, when considering the possible functions of dreams, it is important to consider where they coincide with or divert from the proposed functions of sleep. While the two are intimately connected, treating them as inseparable is ill-advised as they clearly denote different phenomena. Sleep is the background state with corresponding neurophysiological activity that likely carry out a variety of different functions, just as the brain does in its waking state. Dreams are one sub-feature the sleeping brain generates, similar to experiences being one feature of the workings of the brain in the waking state, and thus it is advised to consider their functions as separate from each other.

2.3.1 Form of Sleep

Sleep is physiological state often considered to consist of two alternating states: non-rapid eye movement (NREM) and rapid eye movement (REM) sleep. This cycle is also referred to as the ultradian cycle, to position it with other chronobiological rhythms such as the circadian rhythm of the wake-sleep cycle. The ultradian cycle progresses in 90 ± 20 minute sequences (Brandenberger et al., 2001).

2.3.1.1 Non-rapid eye movement sleep

NREM accounts for sleep stages N1–N3 (previously 1–4), alternatively named NREM1, NREM2 and slow wave sleep (SWS) respectively, during which cortical oscillatory activity is progressively hypersynchronized (Weigenand et al., 2014). We spend the majority of our sleep in N2. NREM is characterized by little or no eye movements, regular local and global slow cortical oscillations at a 0.5 to 4 Hz frequency (esp. N3) [19], sleep spindles and K-complexes (esp. N2) (de Andrés et al., 2011). Sleep spindles are brief activity bursts that begin to locally feature in the

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[19] However, this separation is made more complex by the findings that slow wave activity can also occur during REM sleep and even wakefulness (Siclari & Tononi, 2017).

lighter stages of NREM sleep and towards the transition to REM sleep. Spindles involve the thalamus and corticothalamic dynamics in specific locations, yet never globally throughout the brain (Vyazovskiy & Delogu, 2014). K-complexes are brief single large delta waves that occur spontaneously in early NREM, but can also be induced by external stimulation.

The dynamical changes in brain activity accompanying NREM sleep have been studied with various brain imaging methods. Cortical effective connectivity was found to breakdown during N3 sleep and the thalamocortical circuits, while remaining active, still lose their ability to interact and produce coordinated and integrated responses (Massimini et al., 2005, 2010). A recent analysis of the functional connectivity of the resting state network throughout the sleep and wake states suggest that instead of viewing functional connectivity as *decreased* in NREM it would better be described as *altered* as it showcases more complex reversed, increased or reduced dynamics compared to REM or wake (Houldin et al., 2021). Interestingly, the resting state network alterations related to networks considered to accompany higher-order phenomena, such as the Default Mode Network (DMN) or frontoparietal network (FPN), suggest possible alterations in consciousness. This adds to the previous study by Chow and colleagues (2013) where NREM sleep was correlated with the uncoupling of DMN, with subsequent recoupling in the REM state. Furthermore, Houldin and colleagues (2021) tentatively suggest a homeostatic function where the purposeful reconfiguration of NREM functional connectivity and its subsequent return to the wakefulness-like configuration in REM increases the cognitive flexibility required for adaptive functioning.

2.3.1.2 Rapid eye movement sleep

REM or paradoxical or desynchronized sleep is defined by rapid eye movements, muscle atonia, and by hippocampus-originated theta waves (6-9 Hz) and ponto-geniculo-occipital waves (PGO), and is unique for mammals and birds. The REM sleep periods are often shorter in length than NREM sleep and the two cycle several times through the night, with the proportion of REM increasing the longer time is spent asleep. The brain activity similarities between wakefulness and REM include fast, low amplitude, desynchronized oscillatory activity (Iber et al., 2007), and the energy cost of REM sleep is either equal or increased compared to wake (whereas in NREM oxygen and glucose metabolism is decreased by 11–40% compared to waking) (Maquet, 1995; Maquet et al., 1990). While the connectivity within REM sleep was remarkably similar to wakefulness with complex and integrated interactions, there were also similarities between NREM overall, and with N1 especially, suggestive of cortical activation similarities in the background state that supports REM and N1. Similarly to the previously mentioned study of functional connectivity by Houldin and colleagues (2021), REM sleep was found to recouple the functional network structures (such as the DMN) first decoupled in NREM sleep (Larson-Prior et al., 2009; 2011).

2.3.1.3 Interplay between REM and NREM

Vyazovskiy and Delogu (2014) have proposed a dynamic interplay between NREM and REM sleep. The slow oscillatory activation of NREM sleep is considered to carry out a recovery phase, which in the up-state enables processing of information and synaptic plasticity, while in the down-state carrying out cellular maintenance. Complementarily REM sleep identifies the network structures that have been sufficiently stabilized and which require more slow wave activation processing.

Conversely to the similarity between REM sleep and wake brain activity, in NREM sleep the cortical network dynamics are significantly faster (Buzsáki, 1989; Nádasdy et al., 1999; Wilson & McNaughton, 1994). An illustrative example into the differences between the neural processing during REM and NREM sleep comes from a head direction study in rodents (Peyrache et al., 2015). Neurons—aptly named *head direction cells*—in the hippocampal post subiculum region fire corresponding to the specific head direction, and together with various other neurons throughout the brain form a broader *head direction system* (Ranck, 1985, cited in Buzsáki, 2019).[20] During REM sleep these cells are found to fire in a corresponding rate to that of waking activity, replicating the firing pattern of pre-sleep situation. Thus, if the mouse were to have a conscious experience, these cells would help cover which way in the dream the mouse would be looking. More interestingly, and less speculatively, however, in NREM sleep the same organized activity persisted, but drifted at ten times the rate than in REM sleep or wake state (Peyrache et al., 2015). Similar temporal compression has since been observed in preparatory preplay of learned visual sequences in humans during wake (Ekman et al., 2017; Huang et al., 2018). This memory replay is suggested to rely on nested hippocampal sequences in form, with the slower time scales related to behaviour containing faster theta-sequences that together cooperate for consolidation (Drieu et al., 2018). When such nesting of theta-sequences is lost, due to, for example, immobile passivity during the spatial experience, the sleep replay itself is degraded.[21]

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[20] Specifically, in addition to the post subiculum, this system includes neurons in the brainstem, mamillary bodies, antedorsal thalamic nucleus, entorhinal cortex, lateral septum, and the parietal cortex (Buzsáki, 2019 p. 107).

[21] In Drieu et al. (2018) the passive situation consisted of a mouse passively riding on a model train, whereas in the active condition the mouse simultaneously ran on a treadmill mounted on the moving train. The latter condition maintained the nested theta-rhythm, whereas in the former the episodic or spatial replay was not present.

2.3.2 Function of sleep

2.3.2.1 Function of NREM sleep

NREM sleepis considered instrumental for memory consolidation (Diekelmann & Born, 2010) and cellular homeostasis (de Andrés et al., 2011). While the cellular "housekeeping tasks" of NREM are essential, they are only noted, as they are likely to have little bearing on the question of dreaming. However, the memory consolidation and simulation functions are arguably more likely to relate to dream formation and thus considered more at length (Wamsley & Stickgold, 2011). For example, in rodent sleep hippocampal activity patterns related to exploration are replayed, and thus argued to help solidify the spatial map of the environment (Lee & Wilson, 2002; Stella et al., 2019; Wilson McNaughton, 1994). This "replay" for memory consolidation is considered to be organized by sharp wave ripples (SWR), likely in coordination with sleep oscillations and sleep spindles.[22] Indeed, spatial memory seems to be impaired when sharp wave ripples are selectively deactivated in rodents (Girardeau et al., 2009).

Suggestion of how preferences for the content to be replayed are set in humans were recently studied by Sterpenich and colleagues (2021) in a brain imaging study combining electroencephalography (EEG) with functional magnetic resonance imaging (fMRI). The participants played two computer games, with contents known to activate specific areas in the brain. One was a face recognition game, where the task was to identify a target face from a set of 18 images and thus associated with the area involved in face recognition, the fusiform and occipital face areas. The second was a first-person maze-navigation game, recruiting especially the parahippocampal place areas involved in scene recognition and memory. Unbeknownst to the participants the game was rigged, and they only won one of the games irrespective of their actual performance. Subsequent sleep was found to increase activation in the brain areas related to the game they had won, suggesting a reward-based motivation for selecting specific memories for NREM sleep replay (Sterpenich et al., 2021). Unfortunately, the participants were not queried on their dream contents and therefore the question of whether this replay was consciously experienced as a dream or not remains unsolved. Furthermore, the study only assessed slow-wave sleep activity and not REM sleep. Tentatively the reward based preferential activity would fit well with studies on dream contents being more positive in NREM sleep (McNamara et al., 2005).

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[22] Additionally, sleep spindle activity was correlated with the refreshment of our brains' learning capacity, suggesting a preceding function for NREM sleep in addition to the retroactive consolidation (Mander et al., 2011).

2.3.2.1.1 *Preparatory spatial and motor simulation in sleep in non-human animals*

The preparatory simulation view—the idea that our internal models are used for anticipatory simulations—is arguably also indirectly supported by neuroscientific research in rodent slow-wave sleep. While these do not account for dream studies per se, as we have no access to non-human offline experiences they point toward spatial anticipatory simulation of corresponding neural circuits during slow wave sleep. Dragoi and Tonegawa (2013) placed rats in a U-shaped maze, with access to two of the aisles restricted with a transparent wall. Chocolate sprinkles were placed at the end of these inaccessible, yet still visible tracks. Subsequent recording of sharp-wave ripple[23] activation in hippocampal place cells during the following night's sleep found not only the activation of cells corresponding to the experienced movements (*spatial replay*), but also those corresponding to the uninvestigated area (*spatial preplay)* (Dragoi & Tonegawa, 2011, 2013). Ólafsdóttir and colleagues (2015) carried out a similar study to uncover whether this replay and future preparation required a previous memory experience of the simulated spatial location. They had rats observe food delivered to a place they had not before visited. During subsequent sleep they found preparatory activation of place cell sequences corresponding to that space during sleep. This would suggest the formation of a hippocampal representation of an unexplored motivationally salient environment during sleep. Similar possible preplay simulation was found in a study that assessed the activation of song-related muscle activation in zebra finches during sleep (Young et al., 2017). They found male zebra finches to preplay more varied and uncoordinated song patterns during sleep compared to their relatively stereotypical performance during the day. Thus, the sleep activity seems to not be fully explained by replay or memory consolidation functions. In the zebra finch study these findings could, however, alternatively also be explained by strengthening the motor program of the stereotypical song by purposefully generating error signals that help make the motor programs more robust (Young et al., 2017).

While such preplay is considered a relatively robust phenomenon, replay—replaying experienced sequence of hippocampal place cell activation during subsequent sleep—is still considered to be a more common mechanism, consisting of repurposing pre-existing cognitive maps and in addition to sleep to also take place during wake following the experience (e.g., Bevandić et al., 2021; Farooq et al.,

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[23] Sharp wave ripples (SWR) are oscillatory patterns only found in the hippocampus and neighbouring areas (Buzsáki, 2006). SWRs are mostly involved in memory consolidation, with extinction of the cells leading to impaired memory formation (Girardeau et al., 2009). Studies of the role of SWR in humans, however, are still lacking.

2019; Foster & Wilson, 2006; Gupta et al., 2010; McKenzie et al., 2021; Ólafsdóttir et al., 2015; Silva et al., 2015; van der Meer et al., 2020).[24] However, despite these caveats preplay still tells us something about the functions of sleep throughout animal kind and thus should also be of interest to those interested in human sleep.

2.3.2.2 Function of REM sleep

There have been various suggestions for the function of REM sleep following its discovery by Aserinsky and Kleitman (1953). These have ranged from removing undesirable cerebral network interaction modes (i.e., removal of parasitic associations due to overwhelming information) (Crick & Mitchison, 1983, 1986), modulation of receptor sensitivity (Siegel, 1995; Siegel & Rogawski, 1988), handling of stressful events (Greenberg et al., 1972), maintenance of catecholamine-containing neurons (Stern & Morgane, 1974), to, for example, warming the brain (Wehr, 1992), to note a few. Despite the differences in opinion of its function, it seems that REM sleep is performing an important function. Restriction of REM sleep leads to cognitive, physiological and behavioural alterations (Demontis et al., 1990; Silvestri & Root, 2008; Vogel, 1975), and in prolonged form to death (Everson et al., 1989).[25] Similarly, lower proportion of REM sleep is associated with an increase in all-cause mortality in humans (Leary et al., 2020; Zhang et al., 2019). Curiously, REM sleep deprivation can also affect an improvement in depression (Vogel et al., 1980) and increase alertness (Nykamp et al., 1998).

The proposed REM sleep functions most relevant to the topic covered here are those that have to do with dreaming. REM sleep has been considered as dream sleep, as REM sleep awakenings consistently are accompanied by recall of subjective experiences. While several memory-related theories have been proposed for emotional, spatial or procedural memory functions the overall conclusion remains unclear (e.g., Siegel, 2001; c.f. Vertes & Eastman, 2000). Currently the evidence seems to best support improved procedural or other more complex forms of learning, yet the role of REM for memory consolidation is far from clear (for a review, see Rasch & Born, 2013).

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[24] Awake replay seems to represent specific past experiences and not preparation for subsequent choice behaviour (Gillespie et al., 2021).

[25] There may be other factors that explain the extreme results from sleep deprivation study in rats related to the deprivation method. For example, the platform method – where the rodent falls in water when entering REM sleep – may contribute to disrupted learning via stress or the effects of getting wet, rather than REM deprivation, as such effects were not found when REM was deprived by a gentler rocking motion (Siegel, 2001).

Some evolutionary theories have also been proposed. Snyder (1966) proposed the sentinel theory, where REM sleep is evolutionarily beneficial as it periodically first activates the animal's brain, then at the end of REM wakes it up to scan its surroundings for possible predators. As reviewed in the previous chapter, the protoconsciousness theory (Hobson, 2009) argues foetal REM sleep to function as a preparatory simulation and prepare the infants' central nervous system. Additionally, REM sleep in all mammals—with the sole exception of the nine-banded armadillo (Affanni et al., 2001)[26]—is accompanied with physiological sexual activation during sleep. However, these are only rarely accompanied with sexual dream content in humans and may point to the diverting functions of REM sleep and dreams.[27]

In conclusion, while there are several theories on the function of REM sleep, the evidence is inconsistent, and the various theories exert their explanatory power at different levels of the phenomenon from conscious contents to cellular housekeeping.

2.3.3 Sleep and the social environment

Humans are unique among primates in their sleep effectiveness. Compared to every other non-human primate humans have the shortest sleep time but the highest proportion of REM sleep (Samson & Nunn, 2015). Why should this be? It may help first to consider the proposed link between cognition and sleep. First, the *sleep-quality hypothesis* states that the nest-building of great apes allowed for deeper and more sustained sleeping patterns, which in turn have given rise to enhanced cognition. Second, the *engineering-hypothesis* argues in the opposite direction, proposing that the greater cognitive capabilities of the great apes have enabled them to build nests. The third argument proposes a mutually inclusive positive feedback loop, where increased cognition has allowed nest-building, which has increased sleep quality in turn enhancing cognition. In humans the situation is more complex, as likely since *Homo Erectus* (or possibly even *Homo Habilis*) humans no longer slept arboreally, but on the ground, supposedly due to changes in their physiological features. This move is arguably both risky and beneficial. It increases the risk of predation, thermoregulation and disease transmission by terrestrial insects, while

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[26] In the armadillo these are present in SWS. Curiously, the nine-banded armadillo is polyembryonic, resulting in offspring that are genetic clones, and thus there is reduced sibling conflict, which may point to a fitness signal function of REM sleep sexual displays (see McNamara, 2019).

[27] An alternative proposal would be that the physiological state reveals the unconscious desire of the dreamer, which must then be symbolically transformed in the dream to avoid disruption of sleep, as per Freud. Here the problem is that people do also have overtly sexual dreams that do not disrupt sleep.

driving towards shared sleeping sites, sustained fire use and—crucially for sleep—the need to optimize sleep efficiency (Samson & Nunn, 2015).

Overall, in social animals sleep is a socially moderated process. As an example, many birds sleep in a row, with birds on either end exhibiting unihemispheric, or asymmetric SWS—sleep with one of the brain halves awake and prepared to react to, for instance, predators—while birds in the middle sleep with both hemispheres. The phenomenon is not limited to birds, but also presents in various marine mammals, such as manatees, sea lions, whales and dolphins (see e.g., Rattenborg et al., 2000). The effects of social isolation, sexual activity and social conflict has been studied mostly in rodents. For example, social conflict seems to increase the amount and intensity of slow wave EEG activity regardless of the outcome, with defeated rats also evidencing a slightly larger increase in NREM sleep (Kamphuis et al., 2015; Meerlo et al., 1996a, 1996b, 2001). In situations of social defect NREM sleep changes were largely related to increased delta-band activity. However, a study assessing effects of chronic social stress on sleep found NREM sleep activity to increase during the recovery, yet not during the stress period itself. Interestingly, an increase in REM sleep activity during recovery was also found.

Social stimuli may thus (also) function on a homeostatic level as a *zeitgeber*, a timekeeper that affects our sleep-wake cycle. The exact mechanism is still under debate and direct and indirect effect have been suggested. Social stimuli may either regulate the phase and period of the various circadian clocks directly or indirectly via photic zeitgebers. Direct influences are considered to function via processes of associative learning. Together, such synchronization of sleep-wake cycles due to social stimuli is referred as social entrainment (Mistlberger & Skene, 2004). Additionally, the influence of societal factors—for example working hours or school schedule—leads to the phenomenon of *social jetlag* (SJL), the difference in sleep time between workdays and non-workdays. While upending the daily schedules on a global scale, the COVID-19 pandemic has reduced SJL by 20 minutes (Korman et al., 2020). There are currently only limited studies on human sleep environments, mostly from western cultures and concerning parent-child sleep practices. A rare exception is a study by Samson and colleagues (Samson et al., 2017) that collected sleep data from modern hunter-gatherers of the Hadza community. They found sleep structure to be more entrained by environmental cues than is the case in Western populations. Furthermore, while the early morning was consistently spent asleep the other times of the night as well as daytime napping evidenced more flexibility. Furthermore, the Hadza social sleep pattern conforms to the sentinel hypothesis, where vigilance tasks and thus sleep turns are shared throughout the night: All of the hunter-gatherers were simultaneously asleep for only 18 minutes during the whole 20 day data collection period, affected by age-dependent chronotype variability (Samson et al., 2017).

3 Operational definitions

Whereas the conceptual definitions help us understand what we are dealing with, the operational definition guides us on how it should be studied. With regards to dream experiences operationalization poses some specific problems. I will go through these topics in turn, with an aim to provide an overview of the methodological challenges and practices for dream research.

Methodological developments in research are often associated with corresponding leaps in the field of study in general, either by confirming or—what is less often the case—discarding previous working hypotheses and spurring new theoretical insights. With the current turbulence caused by the replication crisis (Gilbert et al., 2016; Open Science Collobaration, 2015a) there is a need to increase the rigour of psychological science, with dream research potentially occupying the most problematic end. Havelock Ellis has noted the literature for dreaming to having "often been overweighted by bad observation and reckless theory" (Ellis 1922, pp. viii). Dream research is in several ways more problematic than many other fields. The sample sizes are often small, the dream reports prone to memory and reporting errors, the theories either too vague or too difficult to operationalize, the background assumptions varied and mutually exclusive. The list goes on. What, then, is to be done?

3.1 How to measure dreams?

Dreams are, by definition, subjective experiences that occur during sleep. A major issue and an explanation for the slow progression of dream research is methodological, arising from the problems inherent in the studying first-person subjective reports from a third person perspective—*heterophenomenology* (Dennett, 2003, 2007). Therefore, the question of how to measure dreams contains the broader question of how to measure subjective experiences.[28] Furthermore, the only

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[28] Here I do not engage with the philosophical debate on whether dreams in fact are experiences at all, as the anti-experiential view is currently widely rejected. However, for developed rejections of dreams as experiences see Malcolm's (1956, 1959) wittgeinsteinian argument, and Dennett's (Dennett, 1976, 1979) *cassette theory* of memory insertion upon waking. For a thorough review and counterarguments, see Windt (2013, 2015).

practically feasible way to gain access to dreams is via retrospective reports obtained after waking. Thus, we are always twice removed from the actual object of study and arrive face to face with the most difficult problems of psychological methodology.

3.1.1 Brief methodological history of modern dream research

The beginnings of modern dream research can be traced back to 1855, when the French publication *Academie des Sciences Morales et Politiques* queried its professional and lay readers on the fundamental difference between dreaming and thinking, as well as any specific alterations in mental faculties accompanying the transition from waking to sleep (Schwartz, 2000). The introspective method gained new and increased interest due to the development of a *direct introspective method*, developed by Alfred Maury in his work *Le Sommeil et les Rêves* (Maury, 1861). He introduced a procedure of introspective dream research which already carries the traces of the modern reporting methods. Maury proposed the following standard procedure: The researcher is accompanied by an assistant whose task is to wait for the researcher to fall asleep in a laboratory setting (specifically, in an armchair) and then depending on the exact research question either stimulate or wake up the researcher according to a fixed schedule. Immediately upon awakening the researcher then proceeds to systematically report the experiences. For Maury (1861), these studies consisted of, for example, tickling the dreamers face repeatedly with a feather. Similarly, Saint-Denys carried out such attempted intrusions in a less rigorous setting by having his servants secretly perfume his pillows (Saint-Denys, 1867/1982, pp. 170–171).

While such a method allows for the analysis of dream contents over a long dream series and thus provides a valuable asset for theoreticians, it is also pregnant with concerns. Already in the 19th century critiques were raised in how it places the researcher both as the object and the subject of the research (Carroy, 2006; Lombardo & Foschi, 2008). This criticism can still be heard for reports analysis in general; the participant by undertaking a dream reporting task may already distort the actual dream contents with either her own or the researchers' assumed preconceptions. In other words, dreams, as many other psychological phenomena, are notoriously susceptible for confirmation bias or the demand characteristics of the environment. The introspective method was further developed by the student of William James, Mary Calkins (1893) to what has been titled the *introspective indirect measure*, which removed the researcher from the object of study and broadly outlined the current practice still used today and detailed below.

3.1.2 Content analysis of dream reports

Most of the studies about dream contents rely on content analysis of dream reports and use the introspective indirect method. All retrospective reports lack the immediacy often considered essential to avoid decay of accuracy. While Rosen (2013) does consider the anti-experiential claim of dreams not being experiences at all as unlikely, she is critical on the received view that dream reports are accurate. This *narrative fabrication view* argues that dream reports are unreliable as they are especially prone to confabulation or fabrication, due to their bizarre content, issues with memory recall, and deficits in higher order processing. Foulkes (1979) compared REM and NREM sleep dream reports from laboratory and home awakenings and found the latter to be more susceptible to rationalization. Marcel Foucault (1904) argued for a view where the unorganized mass of dreams is systematically organized and reassembled upon waking to form a coherent logical form.

3.1.2.1 How to collect dream reports

In preferred practice, dream reports are collected either in written form or spoken and transcribed to text at a later date (Schredl, 2010; Sikka, 2019). Written reports have the benefit of being better organized, but they are often shorter and less bizarre (Casagrande & Cortini, 2008). The dream is written down directly upon awakening to minimize content errors or additions.

In laboratory dream log studies the participant sleeps in a sleep laboratory, often with a physiological sleep monitoring device. The participant is then awoken, usually from a specific sleep stage dependent on the research question, and asked to immediately report everything they remember of their dream experiences. The setting allows for repeated awakenings throughout the night. The laboratory approach has its benefits in that it allows for repeated awakenings and a valid monitoring of the sleep stage. Therefore, such data can answer questions of changes in dream contents throughout the night or between sleep stages. Such data collection is, however, laboursome, and unfeasible for larger samples, as they require not only the subject to sleep non-consecutive nights at the laboratory, but also the presence of laboratory personnel and costly equipment (Sikka, 2019). The laboratory surroundings themselves can affect the dream experience (e.g., Schredl, 2008), compromising the generalizability and the ecological validity of the acquired reports

Alternative to the laboratory dream log is the home dream diary. This is the most used method in dream research, as it is cost-effective, and avoids at least some of the problems of generalizability and ecological validity of the laboratory setting. Most often the participants undertake to keep a dream diary for a specific set of time and either report their experiences upon natural awakening or are awoken at a preset time. Occasionally such studies are accompanied by home-based sleep monitoring devices, which allow for collection of various sleep parameters or even set awakenings. Such devices are often either of low validity in assessing the parameter or hard to come-by (Kelly et al., 2012). As a result, most of the reports derive from morning awakenings and thus only represent a subset of dream experiences (Domhoff, 1996).

Additionally dream reports can be supplanted by additional probes and questions. For example, the participant may be asked whether or not they would consider the reported dream a nightmare, what is its emotional tone, or whether it pertains to some aspects of their waking life.

3.1.2.2 How to analyse dream reports

The received narrative reports are analysed using specific content analysis methods, depending on the question at hand. Content analysis is painstaking and laboursome work, also plagued with several sources of error. These risks can be mitigated by standardizing the reporting practices, having two or more independent analysers code the reports separately and by considering the analysis methods for specific questions. The raters should be either at minimum two experts trained in the rating procedure or, alternatively, rated by the person who reported the dream. Depending on the analysis method they should either only rate the explicitly produced content, or they can also infer the content or action from the context. The reports are prepared for the analysis by removing unrelated content (waking thoughts, repetition, marginalia), anonymized, and their order reorganized. Often the reports that fall under a certain length are removed from the analysis.

Among the over a hundred varied content analysis methods the most commonly used is the Hall and Van de Castle coding system (HVdC; Domhoff, 1996) that provides a thorough inventory of dream contents. It is also the method used in the normative data against which various reports are still compared (Sikka, 2019). There are also specific content analysis methods to score, for example, threatening events (Revonsuo & Valli, 2000) or bizarre elements (Revonsuo & Salmivalli, 1995) in narrative reports. Already in the 1970's Winget and Kramer (1979) listed altogether (Schredl, 2010; Sikka, 2019) over 130 dream scales and rating systems to select from. Regardless of the scale, the raters usually proceed by independently analyzing the anonymized reports. The preferred instances are then annotated either on the level of words or sentences, or at the level of the report. The resulting scores are then compared, and possible disagreements either solved by consensus decision or a third rater, or if the disagreement persists, discarded from the analyses. The interrater reliability can then be assessed as an amount of (dis-)agreement, either in percentages, Cohen's interrater Kappa values or in some cases Krippendorff's Alpha

(Oleinik et al., 2014). Low interrater reliability indicates noise in either the data or in the coding procedure, and the data suggested to be unusable. Alternatively, dream reports have recently been increasingly analysed with the aid of automated algorithms, either using the HVdC method (Fogli et al., 2020) or a graph-based analysis (Mota et al., 2014, 2020).

3.1.2.3 Problems in dream report analyses

Due to the subjective nature of the dream experience, it is very difficult to control self-censorship or other reporting biases. The participant may wish to suppress certain types of reports due to shame, fear or other internal or external motivation. This may bias dream reports to appear, for example, less sexual, violent or otherwise contain features that are less socially normative or accepted. The demand characteristics of the reporting environment may at least partially explain the finding that dream reports collected for dream research differ in content from those encountered in settings where attention is specifically aimed at dreams and their content, such as in psychotherapeutic settings (e.g., Halliday, 1992). Additionally, there is interesting evidence that the findings achieved through content analysis are affected by who conducts the analysis. In studying emotions in dreams, Sikka and colleagues (2014, 2021) have found that self-rated emotions in dream reports are far more positive than externally rated emotions, which in contrast underscored negative emotional valence. This is likely due to, either, the way in which reporting is carried out; we tend to not overtly explicate positive emotions of, say, a pleasant night of academic discussions in good company, thus making positive emotional content less available to an external rater going by the report alone. The dreamer herself on the other hand has access to the broader episodic reconstruction of the report and its context to infer additional emotional states. Alternatively, one could argue that the subjects themselves are not in fact coding the emotional content in the same sense as the external rater is, but are in fact retroactively generating additional data, affected by the current emotional state of the subject and biases positivity. With regard to emotions this reporting problem seems highly problematic. If we have two similar methods of analysing the emotional valence of the dream reports (or, rather, in the case of external evaluation to analyse *the report*, yet for the subject to analyse *their experiences*) which produce opposite outcomes, it would seem we can tease out the results we wish by methodological decisions even before commencing on the data gathering. Furthermore, the question of which of the two ways of reporting produces more realistic results is left unanswered. It seems obvious that one of the methods is invalid, as the results—especially with regards to positive emotions—are so divergent.

Theoretically this poses a problem for all content analysis research, not just those looking at emotionality in dreams. However, it is more problematic for theories that have overtly included emotional responses into their theoretical basis; such as, for example, the emotion regulation theory (Nielsen & Lara-Carrasco, 2007). Similarly, such reporting biases may pose problems for the graph-analytical approach, where word-level analyses are carried out to assess the coherence or the emotional valence of the dream.

3.1.3 Other ways to measure dreams

3.1.3.1 Most Recent Dream

Another commonly used measure to collect dream reports is the Most Recent Dream (MRD) method. It is often used in cases where only one dream is collected per participant, or in classroom or other such settings that are removed from the sleeping environment. In short, MRD consists of participants writing down their most recent dream as accurately and completely as possible (Domhoff, 1996). What this method gains in its ease of use it arguably loses in accuracy. As the most recent dream may derive from even weeks or months before the report it is liable for memory distortions, reconfiguration, as well as possibly biasing such data toward more emotional or meaningful dreams, which are more likely to survive the usual forgetting of dreams. As such it should be considered more as a method to study dream remembering than dream experiences (Sikka, 2019).

3.1.3.2 Dream questionnaires

Dream questionnaires allow us to ask more general questions about peoples' dream experiences. Even further removed from the actual experience they are subject to similar memory biases as the MRD, and even more susceptible to self-perception biases (i.e., instead of answering the question "do you have frequent nightmares?" accurately the participants may instead answer whether they consider themselves to be the kind of person who has frequent nightmares (Sandman, 2017), which may be liable to several other confounding factors.

In a study comparing dream report with dream questionnaire data on the same participants, Bernstein and Belicki (1996) found them to potentially reflect different aspects of dreaming, with questionnaires more likely to track the daily concerns and be influenced by the personality type of the participant.

3.1.3.3 Neuroimaging dreams

While most of the neuroimaging research related to dreams are to do with measuring the sleeping brain and correlating the relationships between various patterns of activation of connectivity dynamics with retrospective dream reports, there are some exceptions. Most notably, a first step toward imaging the visual content of our dreams was conducted in a study by Horikawa and colleagues (2013). Using functional magnetic resonance imaging (fMRI) they were able to predict the persons' experienced N1 sleep images based exclusively on neuroimaging data. Three participants slept in an fMRI scanner and were awoken every ~340 seconds to report their dream contents. The dream reports were subsequently analysed for repeating visual elements, grouped into approximately 20 individual categories per participant. Next, an algorithm was trained to recognize patterns of neural activity related to these categories using images derived from the internet. Base on this training dataset the algorithm was able to accurately correspond the reported visual imagery from the dream with the brain imaging data where the report came from at 60% accuracy.

While such machine-learning methods are currently relatively common within neuroscience, and have recently been employed to, for example, characterizing the neural substrate of emotional experience (Horikawa et al., 2020), we are still relatively far from what has been titled the *Dream Catcher* (DC) test (Revonsuo, 2006). It is proposed to truly get to the brain-base of phenomenal consciousness, and consists of hypothesized future state where a team of researchers are able to reconstruct the dream as a multimedia computer animation solely on the data of brain activity. This resulting animation is then successfully compared to other animations based on the subjective reports alone. DC test is ambitious in that it not only aims to uncover the neural correlates of consciousness, but its *constitutive mechanism*. The neural signature of a successful DC…

> "…must have reflected the patterns, organizations and the dynamics of phenomenal features at the phenomenal level in the brain" (Revonsuo, 2006, p. 2)

Finally, one way to measure dream contents is to use the specific subset *lucid dreaming*. Lucid dreaming refers to a situation where the dreamer regains enough metacognitive capacity—i.e., reflective consciousness—within the dream to understand it as such, and in some instances then to an extent can control the dream (Fenwick et al., 1984; Filevich et al., 2015). This phenomenon allows for interesting scientific possibilities as it is in some cases possible to reliably communicate from within the dream experience using eye movements and contractions of facial muscles. In a set of four studies researchers were able to establish two-way communication with the participants experiencing REM sleep lucid dreaming. Furthermore, the participants were able to, for example, receive and accurately respond to math questions, to count and, to carry out semantic discrimination (Konkoly et al., 2021). While the equivalence between non-lucid and lucid dreaming experiences remains uncertain, reports seem to verify the spatiotemporal structure within which the individual resides, even if there are differences in content (such as decreased bizarreness in lucid dreaming, Yu & Shen, 2020). This would point to the usefulness of lucid dreaming in uncovering the phenomenal features of the dream world proper.

3.2 How to measure sleep?

The brain goes through various psychophysiological states during sleep. Methodologies to assess and quantify sleep has gained significantly upon the development of neuroimaging methods. Here I will briefly overview methods to assess and measure sleep, inasmuch they relate to methods applicable to dream research.

3.2.1 Electroencephalography

Electroencephalography (EEG) indirectly measures the electrical activity of neuronal populations via electrodes on the scalp. EEG was applied to assessing the sleeping brain almost immediately after its invention. Loomis and colleagues (1937) observed sleep to contain distinct psychophysiological states and were first to quantify specific NREM sleep stages. Following the detection of rapid eye movements during sleep (Aserinsky & Kleitman, 1953) the use of EEG in sleep research gained a very strong position within the methodological practice in both research and clinical uses. It is still the gold standard in clinical and practical assessment of sleep parameters, such as sleep stage, sleep onset latency (SOL), REM sleep latency (REML), total sleep time, REM sleep percentage, wake after sleep onset (WASO), and specific sleep-related characteristics such as the appearance of sleep spindles, or specific frequency bands or oscillatory patterns. In sleep research and clinical sleep assessment the sleep-specific EEG-based assessment combined with other variables, such as eye movements (electro-oculography) and muscle activation (electromyography) is called polysomnography (PSG), often augmented with heart rate, breathing or blood oxygenation measures (Deak & Epstein, 2009). While there are some home-based sleep monitoring devices for consumer use that arguably use electrodes to pick up electric activity in the brain they are only rarely rigorously validated (Kelly et al., 2012), and thus the use of EEG for sleep analysis is mostly constrained to sleep laboratory settings (see section 3.2.3).[29]

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[29] With the exception of ambulatory PSG (McCall et al., 1992)

3.2.2 Other imaging methods

In addition to EEG other new neuroimaging methods have also been utilized in understanding of sleep, such as functional magnetic resonance imaging (fMRI) which tracks hemodynamic changes in cerebral blood flow, positron emission tomography (PET) which tracks, for example, the metabolic activity of cell bodies with the aid of radioactive tracers, which allow for a more detailed dynamic maps of the activity within the sleeping brain, albeit with significantly coarser temporal resolution compared to EEG. Recently these methods have also been successfully combined to generate more detailed images of the spatiotemporal dynamics with fMRI-EEG (e.g., Czisch et al., 2002; Duyn, 2012; Piorecky et al., 2020). While there have also been developments in combining PET and EEG, or even trimodal PET-MR-EEG methodology (e.g., Golkowski et al., 2017; Rajkumar et al., 2017; Shah et al., 2017) only rarely have these been utilized for sleep research (see e.g., Hasler et al., 2013, where PSG was used to correlate the PET-observed neural activity with REM sleep). Functional near-infrared spectroscopy (fNIRS) is another relatively new addition to the methodological fold. It traces the changes in light-absorbance in the cortex using near-infrared range (780–2500nm), and can be used to infer cortical brain activity also during sleep (Igawa et al., 2001; Nguyen et al., 2018; Näsi et al., 2011; Pierro et al., 2012).

In addition to imaging, the brain can also be stimulated or perturbed during sleep. When combined with, for example, EEG this allows for the assessment of various system or connectivity level indices. External perturbation can refer to the controlled use of, for example, an olfactory or auditory stimuli during sleep, or perturbing the whole wake-cycle by sleep deprivation (e.g., Scheinin et al., 2021; Terzano et al., 1990). More often in this context it is used to refer to using either a single or a burst of multiple magnetic pulses delivered to the scalp which then disrupt the electric activity of underlying neuronal populations (transcranial magnetic imaging, TMS) or electric stimulation with either alternating (tACS) or direct current (tDCS) during sleep. TMS has been used to assess the level of consciousness during various stages of sleep (Lee et al., 2019; Massimini et al., 2005, 2010; Nieminen et al., 2016; Tononi & Massimini, 2008) or to trigger slow waves (Massimini et al., 2007). Both means of electric stimulation have been used, for example, to uncover the role of sleep spindles (Lustenberger et al., 2016) or SWS (Garside et al., 2015; Marshall et al., 2004. See also e.g., Eggert et al., 2013) in memory consolidation, or to increase subjective sleep quality by stimulating SWS (Mohebbian et al., 2021; Robinson et al., 2018).

3.2.3 Other sleep assessment measures

While polysomnography is the most frequently used method to measure sleep in clinical and research settings, other more feasible options for tracking sleep in non-laboratory settings also exist. Most of such devices are designed for consumer use and their clinical value is under debate. Such devices often lack proper validation against PSG, and thus the accuracy of their information remains questionable. Nevertheless, a reliable and valid portable measure for sleep parameter assessment would greatly benefit both sleep and dream research and increase the ecological validity of the findings.

Other sleep assessment measures include the *Nightcap*, previously REMView, which tracks eyelid and body movement recordings to detect various sleep stages and other sleep parameters (Ajilore et al., 1995; Cantero et al., 2002). Validated against PSG data the Nightcap was able to detect wake, REM and NREM sleep at 87% (Ajilore et al., 1995) and sleep onset latency at 93% accuracy (Cantero et al., 2002). Similarly promising results have been obtained for ZEO wireless sleep monitoring system, which uses a light headband with three brain activity sensor pads. It has been validated against PSG and found to detect sleep stage at 75% percent accuracy, and distinguish sleep from wakefulness at over 90% accuracy (Shambroom et al., 2012). Later these findings were amended with an additional study without the conflict of interest in affiliation to the manufacturer of the first validation. The findings were mostly corroborated, with an overall accuracy of 72.7% with a specific difficulty of distinguishing stage wake (40.8%) (Griessenberger et al., 2013). Unfortunately, neither Nightcap nor ZEO are commercially available anymore.[30]

Additionally, there are a number of sleep measurement devices based on movement detection. The most common of these is the actigraph, a wearable accelometer that tracks motor activity, usually worn in the wrist, hip or ankle (Cellini et al., 2013; Conley et al., 2019; Kosmadopoulos et al., 2014). Problem with actigraphy is that as it is based on motor activity it may overestimate total sleep time and other wake-related measures, such as WASO, SE, and SOL. A recent meta-analysis found actigraphy-based measure to consistently overestimate sleep and to underestimate wake, this trend being more pronounced in people with chronic conditions (Conley et al., 2019). It is nevertheless suggested as an adjunct measure with other measures, such as PSG (Morgenthaler et al., 2007). Actigraphy has been

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[30] Another commercially unavailable method, nonetheless used in sleep research in Finland is the Static Charge Sensitive bed. It was found to agree with PSG in 81% of REM/NREM classification and to distinguish wake from sleep, yet had problems in distinguishing NREM stages (Alihanka & Vaahtoranta, 1979; Salmi & Leinonen, 1986).

used for sleep stage classification, and while it can detect REM sleep it, too, has problems in distinguishing between various NREM stages (e.g., Lee et al., 2019). The ŌURA ring is another wearable device that can track sleep. In addition to the triaxial accelerometer, it includes a gyroscope, two infrared light-emitting diodes, optical pulse measurement using photoplethysmograph, and a temperature sensor. It has been found to be 94–96% accurate in measuring sleep, while sleep stage and wake classification were considerably poorer at 48–65% (Altini & Kinnunen, 2021; de Zambotti et al., 2019). Sleep stage classification can be increased combining the accelometer data with circadian features (Altini & Kinnunen, 2021). Another movement-based measure is ballistocardiography-based sleep tracker Beddit. It is a thin sensor placed under the mattress topper and measures heart rate, movement, and breathing, as well as external stimuli, such as sound (Paalasmaa et al., 2014, 2012). While it is based on the same methodology as the Static Charge Sensitive Bed, the validation of Beddit itself prior to this thesis consists of small samples with individual parameters, such as accuracy in measuring respiration in a single subject (Paalasmaa et al., 2011) or heartbeats (Paalasmaa et al., 2014).

In conclusion, while several options for non-laboratory-based sleep measurement devices exist they either have problems in distinguishing wakeful rest from sleep and/or are relatively poor in reliably detecting sleep stages. As such their value for sleep and dream research remains limited.

4 Theoretical considerations and empirical research

Wittgenstein stated psychology to suffer from conceptual confusion and an overreliance on the statistical method (Wittgenstein, 1953/2009, p. 232e). The recent replication crisis has arguably attested to this assessment (Open Science Collaboration, 2015b). While the advent of big data allows for more rigorous statistical testing, it also increases the risk of confusing description with explanation. It is therefore essential that theoretical development proceeds in lockstep with methodological advancement. If we take the principle of unity of sciences at face value, each different aspect of psychological phenomena should eventually be explainable and understandable via unifying mechanistic or statistical theories (Craver, 2006, 2007; Levy, 2016). Such theories should be not only descriptive, but provide novel risky hypotheses, be internally cohesive, and aim at explanation on various levels (for a flat, non-level view, see Levy, 2016). Alternatively, we risk ending in a state of Baconian science of various descriptive theories with very limited explanatory or predictive power. Arguably, the most scientifically difficult psychological phenomena to explain are those which refuse behavioural operationalisation, rely on first person retrospective reports, and are strictly internal in their manifestation. Dreams tick all of these boxes.

4.1 Multilevel framework as an organizing principle

Cognitive neurosciences and psychology have recently been proposed to seamlessly merge as we reach a cohesive enough mechanistic explanation via levels-based explanation (Craver, 2007).[31]

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[31] There is an ongoing debate on the use of levels concept to begin with, with, for example Guttman (1976) seeing them not only flawed but “dangerous” to scientific thinking (p. 112). For a more optimistic treatment, see e.g., Brooks (2017).

4.1.1 What are levels of organization?

Levels of organization usually refer to the part-whole relationship as an underlying structure of nature. There are two ways to look at levels of explanation in science. First is the reductionist view, often contributed to Oppenheim and Putnam's layer-cake model (Oppenheim & Putnam, 1958). Following the deductive-nomological model (Hempel) they consider six levels that reduce hierarchically from the higher to the lower, from social groups to multicellular living things, from cells to molecules and from atoms to elementary particles. These levels have their own vocabularies, laws and science. Each lower level contains every higher level, yet the highest inhabited level is considered the "proper" level for each thing. This leads to the conclusion that—via what they call *microreductions* between levels—all psychological phenomena can in principle eventually be explained by the laws governing elementary particles (Oppenheim & Putnam, 1958). This view has since then been rigorously attacked, and, for example the role and commonality of microreductions is uncertain.

One attack against the reductionistic view and thus the layer-cake model was proposed by P. W. Anderson with the example of quantum theory (Anderson, 1972). He showed that at different levels or categories of processing new structures and phenomena appear. This is how we get the concept of *emergence*, where sufficient complexity creates higher order phenomena, not reducible to their subsequent parts. Furthermore, the layer-cake model seems incommensurate with multiple realisability—the view that the same kind of phenomenon can be realised in various different systems, substances or processes (Craver, 2005; Putnam, 1975).

Another influential levels-based approach is the mechanistic approach proposed by Craver (2007). He proposes nature to be composed of ontological levels defined by their constitutive roles as parts within a larger mechanism (Craver, 2007, p. 188–189). Craver refers to several different ways the term of levels is used in cognitive neuroscience, for example, in abstraction, analysis, behaviour, complexity, explanation, action, or organisation (Craver, 2007, pp. 163–164). In Craver's analysis levels are unstable and locally defined. Craver's multilevel framework contains levels that are decomposed to their component parts based on the explained phenomenon. The components themselves are related spatially, temporally and by activity. This approach fits well fit the broader multilevel explanation framework (see e.g., Bechtel, 1994, 2011; Craver, 2007) seen as the most fruitful way to understand biological phenomena as unified and complex, and has influenced the Biological Realism approach to consciousness of Revonsuo (2006). In short, the multilevel framework consists of understanding the phenomenon at hand by breaking it down into microcomponents at each level of explanation. The hierarchically organized levels are, first, the constitutive, or downward looking explanation, containing the lower level mechanisms that give rise to the phenomena (e.g., specific neuronal activity patterns or dynamics). It aims to explain the constituent parts that are causally related to the emergence of the phenomenon. Second, the etiological, or backward-looking level of explanation, consists of the causal history leading to its occurrence (i.e., its proximate, ontogenetic, and ultimate causes). The third level consists of the contextual, or upward-looking explanations, of what are the surrounding features within the system in which the phenomenon is situated. This division into the three layers allows us to proceed more carefully toward the goal of an exhaustive explanation. At its very core lies the idea of cross-disciplinarity and equality between viewpoints (see Revonsuo, 2006; Valli, 2011). Considering consciousness as subjective experience to be a natural biological phenomenon of the brain and thus applicable for a multilevel framework consideration, it follows that dreaming, too, should be applicable for such treatment.

4.1.2 Dreaming in a multilevel framework

Positioning dreaming in a multilevel framework allows us to better grasp the interdisciplinary relations as well as to evaluate strength and weaknesses of specific existing theories: what features do they cover and which omit, whether the theories are mutually non-exclusive by virtue of, for example, explaining at different levels. Valli (2011) has used the multilevel framework to position dreaming as the explanandum phenomena.

The constitutive level for dreaming involves the mechanism by which dreams are formed or generated. While there has been progress in uncovering the neural correlates of dreaming (Siclari et al., 2017), critical remarks of this endeavour have been presented (Ruby, 2020) and thus far the prediction of whether or not a person had a dream experience based on EEG data alone has failed (Wong et al., 2020). It should also be noted that while the uncovering of neural correlates is informative, they themselves don't yet answer the question of what is the causally constitutive mechanism for dream generation. Additionally, the constitutive endeavour has previously concentrated on understanding the mechanism for REM sleep generation as a model for dreams (for example the Activation-synthesis and AIM theories, Hobson, 1988; Hobson et al., 2000; Hobson & McCarley, 1977), and thus have left out the constituent mechanism for NREM sleep or sleep onset dreaming (Valli, 2011).

As noted previously, the etiological level contains the proximate, ontogenetic and ultimate causes of the phenomenon. In the case of dreaming, the proximate, i.e., immediate causes should include i) the neural level of the events immediately preceding the dream state generation, and ii) the psychological level, i.e., the higher level processes of memory sources, attention, first and second-order awareness, for example (Valli, 2011). The ontogenetic causes relate to the life history of the individual, and thus contain the causal impact reaching from embryonic influences to the experiences preceding the current situation. As such it precedes in lockstep with cognitive and neural development throughout the lifespan of the individual, likely reflecting the dynamic of external impacts on gene activation. Finally, the ultimate causes refer to the question of why, in a biological sense, dreaming has been selected for, or how to explain its continued existence if it was not a target of selection.

While the multilevel explanation model emphasises the evolutionary explanation, it is also one with highest probability of error. Despite its ubiquity, evolutionary theory—or evolutionary theories—is often misconstrued and overused. Fodor and Piattelli-Palmarini (2011) point to an intensional fallacy in the way natural selection is usually considered: the fact that organisms with adaptive traits are selected is confused with the claim the organisms are *selected for* their adaptive traits. In the end we have no way of knowing whether dreaming is a by-product of consciousness in general (or some other feature of matter or structure); whether the supporting structure of conscious experience has an offshoot in the form of dreams. They might have been carried over due to being useful in answering some pressure in the environment or within the organism, or they might have been carried over for no specific reason, as spandrels. One could even make the argument that dreaming is adaptive while consciousness in its waking form may not be. Some assumptions are, however, likelier than others.[32] Owen Flanagan (2001) has argued dreams likely to rest on the side of spandrels[33]; as a non-adaptive phenomenon. Whatever the answer to the adaptive function to dreaming may be, it should nevertheless be a question to be addressed by any proposed theory.

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[32] As reviewed in the previous chapter 2.2.2. various evolutionarily informed accounts on dreaming have been proposed. An evolutionary background not covered in detail is that of genetic conflict—which can be found, for example, behind attachment dream theories (for example, for an infant sleep view see McNamara, 2014), which sidesteps the need of functionality while preserving the evolutionary background. While this account is too broad to cover here, the reader is directed to McNamara (2002), where a case for paternally expressed genes regulating developmental REM sleep is made in detail. It argues REM sleep to stand on the side of the paternal and against the maternal genetic aims.

[33] The term spandrel denotes an architectural feature of in the cathedral of San Marco, where the beautiful spandrel structures were necessary outgrowths of the overall structure, but themselves showed no specific function. They were later ascribed an aesthetic function. They serve as a metaphor for non-adaptive functions in evolution and have come to be used as a shorthand for any non-adaptive feature (Gould & Lewontin, 1979).

4.1.3 Considerations for evolution of sociality

Humans are quintessentially social compared to other mammals. This has led some theoreticians to describe humans as an *ultrasocial* species (Gowdy & Krall, 2016; Pagel, 2012; Tomasello, 2014; Williams & Bliss-Moreau, 2016). There is a longstanding debate within evolutionary biology concerned with the evolution of sociality and cooperation. It is further complicated by the context dependency of such behaviour, which suggests the underlying social aspects need to be considered in explanations of altruistic behaviour (Boyd et al., 2003; Fehr & Fischbacher, 2003; Fehr & Rockenbach, 2003). It is likely that this quintessential sociality is also reflected in our dream experiences. Therefore, a brief introduction to how cooperation and altruism have been treated within evolutionary biology could help us better understand the social evolutionary pressures under which dreaming has arguably been under.

In general properties may evolve by three distinct ways. First, features may be adaptive. This means that these inherited properties have proven successful in a certain ecological niche aiding in reproduction and survival. It should be noted that adaptiveness does not equal optimality or “correctness”, merely that this feature has outperformed other simultaneously existing features. Nor does it mean that the feature is still adaptive in the current environment. There are several features that are remnants of previous successful adaptations that have since become useless due to changes in either environmental conditions, or in the species. If these have at best little cost they may continue to linger. Second, features can be spandrels. This means that they themselves have not served an adaptive purpose but are intertwined with other adaptive properties. Third, the features may just be the result of random noise.

The long-standing and rather fierce debate of cooperation and prosociality within evolutionary theory and sociobiology was sparked by the biologist J. B. S. Haldane and his thought experiment. The argument is as follows:

> "What is more interesting, it is only in such small populations that natural selection would favour the spread of genes making for certain kinds of altruistic behaviour. Let us suppose that you carry a rare gene which affects your behaviour so that you jump into a river and save a child, but you have one chance in ten of being drowned, while I do not possess the gene, and stand on the bank and watch the child drown. If the child is your own child or your brother or sister, there is an even chance that the child will also have the gene, so five such genes will be saved in children for one lost in an adult. If you save a grandchild or nephew the advantage is only two and a half to one. If you only save a first cousin, the effect is very slight. If you try to save your first cousin once removed the population is more likely to lose this valuable gene than to gain it. But on the two occasions when I have pulled possibly drowning people out of the water (at

> an infinitesimal risk to myself) I had no time to make such calculations. Paleolithic men did not make them. It is clear that genes making for conduct of this kind would only have a chance of spreading in rather small populations where most of the children were fairly near relatives of the man who risked his life. It is not easy to see how, except in small populations, such genes could have been established. Of course the conditions are even better in a community such as a beehive or an ants' nest, whose members are all literally brothers and sisters." (Haldane, 1955, pp.44).

In short, it attempted to answer why we help other people, given that our own survival and interest would seem to be of greater importance. It should be noted that Haldane was preceded by Fisher (1930) who noted on the synonymous topic of why evolution would have favoured distastefulness in insects as it seems to be of little survival value for the individual to taste unpleasant:

> “the selective potency of the of the avoidance of brothers will of course be only half as great as if the individual itself would be protected” (Fisher, 1930, p.159)

Haldane and Fisher did not consider the problem of altruism in any greater detail. The first plausible solution for the question of how altruism may have evolved was formalized in the 1960’s by the British geneticist William D. Hamilton in what is known as the Hamilton’s rule. The rule states that natural selection will favour social behaviours if and only if $rb > c$. In the formula b denotes the behaviours effect (benefit) on the reproductive success of others, c is the effect (cost) of the behaviour on one’s own reproductive success, and r a relatedness coefficient, indicating the probability of sharing identical alleles between the participants (Hamilton, 1964). These two views leave us with a problem: clearly we do not indulge in kin level calculations when faced with situations demanding altruistic decisions, and thus—as Haldane notes—this model would best fit very small communities. Additionally, Hamilton’s rule itself is considered too general and inexact.[34]

It should be noted that the past debate over whether kin or group selection is correct was only slightly affected by the fact that the formalism of the multi-level explanation provided by Price (1970, 1972) (an alternative way to partition the “Price equation”) is identical to Hamilton’s rule, just following a different partition that

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[34] A modified version of the Hamilton’s rule may clear this problem. The rule can be restated, by increasing the level of abstraction and viewing the terms as population statistics, that do not only consider the individual participants but the broader statistical association within a population between both the organisms’ and the social partners’ genes and reproductive success (Queller, 1992).

considers groups instead of individuals (for an extensive comparison, see Birch, 2017). What is more, the necessity for relatively small communities proves problematic when met with the scale of human social organization. It should be noted that both Hamilton and Haldane considered their model as inadequate for explaining human level cooperation or altruism, and Hamilton explicitly proposed a more indirect and context-dependent mechanism to the kin recognition often connected to the idea (West et al., 2011).

Of course, most cooperation between humans is mutualistic and not altruistic; motivation for cooperation may be punishment avoidance, reputational or reciprocal benefits, immediate gain or other factors. Mutual benefit thus uncovers another evolutionary dilemma: How and why have humans come to join and interact peacefully with unknown strangers—or in other instances punish and attack them? The peaceful joining together allows for roaming bands to form tribes, which in turn allows for the structural regularities observed in social networks, that have been put forward as essential in developing large-scale cooperation.

Compared to other animals, humans in foraging societies are uniquely dependent on others for survival (Clutton-Brock, 2009). Taken together it currently appears that only 17 extant species are known to organize into advanced societies based on altruism, cooperation and division of labour. These range from amoebas to wolves, and from bees to baboons—and also, humans (Wilson, 2019). Dependence on others and mutual aid is considered a reason for the success of the human species (Burkart et al., 2009; Clutton-Brock, 2009; Kaplan et al., 2000; Tomasello et al., 2012). However, it creates problems of coordination. When survival is contingent on group social cohesion the problem of how to avoid rupturing this willingness to engage in mutual aid with group members becomes essential (Sugiyama, 2004). The key hallmarks of human life-history traits—long lifespan, delayed reproduction, intergenerational and asymmetric benefit transfers both from adults to juveniles and between adults, and our highly complex nervous system—are all dependent on the relatively low mortality rate of humans (Hill & Kaplan, 1999; Sugiyama, 2004). Altruism in human populations seems to covary with a phenomenon of costly punishment, where people punish others from mis-stepping the social norms even if it were at a cost for themselves (Henrich et al., 2006). Despite societal variance in how eagerly people engage with costly punishment it nevertheless seems to be universally present and is considered to point towards the gene-culture coevolution. One suggested explanation on how this interband cooperation came to exist is cultural inclusive fitness (Birch, 2012). When there is intergroup migration—as Hill and colleagues (2011, 2014) have found to exist in modern-day hunter-gatherers—extended acquaintance, friendship and kin networks are formed. Additionally, in extant hunter-gatherers cultural practices and norms are correlated across two degrees of separation (Apicella et al., 2012). Birch (2012) considers that such shared cultural background would propagate similarly as genes for altruism, by currying favour differentially to those sharing the same beliefs or values, leading to the evolution of prosocial norms and behaviours which eventually enable the formation of societies far greater than the 15–150 found in bands of chimpanzees (or in average Facebook friend lists, see Dunbar et al., 2015; Hill & Dunbar, 2003).

One way to measure such dynamics is via economic games. In an illuminating study Apicella and colleagues (2012) carried out public goods games within various Hadza hunter-gatherer tribes. They found high inter-camp and low intra-camp variance in donations, and crucially, that similarly cooperative individuals were likely to form ties be they kin or non-kin. Social proximity was found as predictive of cooperative behaviour as genetic proximity and camp co-residence, suggesting a major role for social networks in explaining cooperative behaviour. Despite the fact that the Hadza are relatively isolated from industrialized societies their social network structures do witness a high degree of similarity with those of modern industrialized societies. This suggests of universality of such social network features. It is in concordance with previous research with animal social networks, and with how populations' social structures affect ecological and evolutionary processes (Kurvers et al., 2014). Furthermore, recent modelling evidence (Koduri & Lo, 2021) suggests that one need not propose a multilevel selection nor submit to the selfish gene model to explain an evolution of cooperation. They found that not only behaviours that increase fecundity (~selfish gene) but also behaviours that decrease the correlation of fecundity between individuals increase the growth rate of the population. Even if selection at the level of group is in this model not required, the role of correlation in the evolution of cooperation does make it understandable why such a model has previously been seen as a viable option.

In conclusion, the remarkably social nature of our species suggests there to have been an evolutionary pressure towards behaviours and mechanisms that increase cooperation and coordination within larger groups. Such "parochial" or in-group altruism has been proposed to account for how wars and violent inter-tribe encounters could have paradoxically lead to the selection of altruistic and cooperative traits (Bowles, 2009). Considering the importance of social relationships in our waking life for health and survival together with the apparent bias for social interactions in dreams a probable evolutionary hypothesis could thus be formed on the interaction between these features.

Finally, why would we even require an evolutionary account of dreaming? After all, there is the likely chance that they will be merely what are known as just-so-stories; post hoc rationalizations of behaviours to bask in the authoritative halo of evolutionary biology (Hubálek, 2021). Doesn't the conceptualization of dreaming as evolutionarily adaptive merely add possible problems instead of resolving them? These are reasonable worries, but if we take the goal of scientific explanation seriously, we have little option. This sentiment was articulated by the Jesuit priest Chardin:

> “Evolution is a light which illuminates all facts, a curve that all lines must follow” (Chardin, 1959, p.219)

later refined by Dobzhansky (1973) into his famous statement

> "Nothing in Biology makes sense except in the light of evolution"

used to argue for theistic evolution. Similarly to the biologist theorizing about the adaptive value of why a woodpeckers tongue coils behind its skull (May et al., 1976) we should theorize on why we dream, even if we were to uncover it as a spandrel (Flanagan, 2001). Given that dreaming seems to be universal, any functional content should be found prioritized throughout studied populations from western industrial (the so-called WEIRD populations; Henrich et al., 2010) societies to the small-scale or nomadic cultures of hunter-gatherers.

4.2 Social dream contents

> “The lists of dramatis personae are very long, and suggest that the dream world is well peopled.” (Calkins, 1893).

While only recently the social nature of our dreams has been considered to account for the function of dreaming (Brereton, 2000; Franklin & Zyphur, 2015; Nielsen & Germain, 2000), the phenomenon itself is inescapable in the literature on dreams. We now know, for example, that 80–95% of dream reports contain other characters in addition to the dream self (Domhoff, 1996; Domhoff & Schneider, 2018; Hall & Van de Castle, 1966; Strauch & Meier, 1996), of which a slight majority are personally known to the dreamer (Domhoff, 1996; Hall & Van de Castle, 1966; Strauch & Meier, 1996). Romantic partners are present in a fifth of dream reports, moderated by the amount of actual wake interaction (Schredl, 2011; Schredl & Hofmann, 2003). Family members are present in 10–30% of dreams, parents in 8–20%, and siblings in 2–7.5% (Schredl, 2013), whereas friends are present in approximately 20% of dreams (Roll & Millen, 1979). Interaction with other dream characters was found to occur in nearly half of the dreams where the self was present, within a fifth them performing a joint activity and in another fifth acting independently (Strauch & Meier, 1996).

Domhoff (1996) reports 45.4% of dream reports as having at least one aggressive and 39.7% at least one friendly interaction, with 7.6% of reports including at least one sexual interaction per report (compared to Strauch & Meier's (1996) laboratory data with only 1% sexual content). Overall Domhoff and Schneider (2018) report social interactions to be present in 93.6% of dreams in the combined HVdC normative data. In cross-cultural studies including small-scale societies aggressive content is considered more frequent than prosocial, with dreamers often being the victims in these encounters (Domhoff, 1996). Furthermore, compared to waking reports collected via an experience sampling methodology (ESM) dreams contain more social content and include more people unfamiliar to the dreamer (McNamara, 2005).

Over half to 80% of dream reports have been found to include instances of mindreading (Kahn & Hobson, 2005). The participants reported twice as often as not of being aware of the mental state of the other characters. Mentalizing in dreams doesn't only refer to the cognitive content of intentions and thoughts, but also to feelings. Kahn and colleagues (2002) studied 320 dream reports collected over a two-week period from 35 participants, who logged the dream characters' relationship to the dreamer as well as the evoked feelings within the dream. Familiar characters evoked feelings in the dream self in 81% of reports, and unfamiliar or generic (e.g., known by occupational role, status etc.) characters 69% of the time. The three most common evoked feelings were caring, joy, and anger, respectively. This order was found in both, the feelings evoked in the dream self by other characters as well as the feelings evoked in the other dream characters by the dream self.

4.2.1 Dream series and social isolation

As noted previously, one approach to assessing dreams is a longitudinal one. While this approach is problematic for generalizability, it allows for a more thorough analysis of a specific person and their development over time. Here such approach is of note as it allows for comparisons between the changes in social situations and dream content. Two such dream series provide an interesting view on the social aspects of dreaming. The first is an analysis on the dream contents of Norman, institutionalized for child sexual abuse. The dream reports from a several years long collection period were compared to the normative Hall and Van de Castle (1966) sample by Bell and Hall (1971). Due to the nature of Norman's surroundings and the offenses he was incarcerated for, the dream content analyses focused first on the sexual content of his dreams. While there was only a one percent increase in sexual content in dreams compared to the normative male data (13% v. 12%, respectively), the content itself was characterized by prioritizing sexual thoughts and phantasy over overt encounters, and the characters involved all of the categories, save for mother, aunts and other personally known females (excluding sister). Overall, the social dream encounters provide some interesting findings. First, while not present in the sexual dreams, Norman dreamt of his mother four to five times more often than the normative sample (10.4% v. 2.4%). Similarly, his sister appears ten times more often than found in the normative sample (7.9% v. 0. 8%), as do strangers (males 30.7% v. 27%; females 22.2% v. 9.7%) and minors (12.2% v. 2.7%). Conversely, his father or any other male relative is completely absent from the over 1300 dream reports.[35] The other known dream characters are mostly fellow inmates and patients, with only a few long-time friends, below the normative proportions. From an event perspective Norman's dreams frequently simulated instances of separation from his mother or sister (i.e., missing a bus or being left behind). Bell and Hall (1971, p. 77) account for these peculiarities of Norman's dream contents to his personal developmental history, with an emphasis on the family system suspicious and isolated from others, with his mother occupying a central role after the father left. The social isolation was exemplified by the fact that Norman and his sister were not encouraged to invite other children to their home. Thus, his sister and his mother were the only continuing relationships over his life. His social encounters in dreams are 1.5 to two times more likely to contain instances of friendly interactions with every other group than male strangers, where he is 1.5 more likely to experience aggressive than friendly encounters. Bell and Hall (1971) note this to evidence the type of content more often found in children.[36] The Norman dream series showcases how dream series data correspond to the hypotheses of an interplay between waking and dreaming social environment. While such analyses are useful, they should be appended by larger samples, ideally by way of generating more generally testable hypotheses.

Another interesting autobiographical dream series is presented by Merei (1994), who collected dreams during and after imprisonment, with a special interest in social relationship dynamics between dreams and waking life. Throughout the three-year incarceration period close relationships were found to persist in dreams, while other, more distant relationships decreased. The proportion of friends dropped to 10% during imprisonment, with fellow inmates arguably replacing this category. The prison inmates, however, continued to populate the dreams also following release. This is similar to Schredl's (2012) finding that approximately 5% of dreams contain references to school friends even when they have not played an active role in the dreamer's life for decades. Curiously they begin to re-occur more frequently again following a waking reminder, such as an upcoming class reunion (Schredl, 2012). Furthermore, a few unpublished dissertations have looked at the impact of social isolation on dream contents, but the results have been inconsistent. Whereas Wood

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[35] Norman reports child sexual abuse perpetrated by his father from the age of four.

[36] In another dream series "Dorothea", Domhoff (1996, p. 142–145) notes the frequent proportion of dreams that contain her parents to remain relatively constant over the 53 years she collected her dreams, despite losing her father at an early age.

(1962) found an increase in social characters following short one-day isolation as well as an increase in REM sleep, Dallett (1973) reported no effects following a briefer eight-hour isolation and home reporting.[37]

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[37] However, she did find a difference before correcting for report length.

5 Aims of the current thesis

In the previous chapters I have presented considerations and issues that call for a careful and rigorous approach to the study of dreams, while simultaneously providing a more general background to address explicitly the social nature of our dream experiences. We have established dreams to be inherently social, even when compared to our waking social life. What is more, dreams often contain intricate simulations of social interactions, with complex forms of information processing, such as mentalizing. I have argued this inherently social feature of dreaming to possibly account for its evolutionary, biologically adaptive function.

While these studies are promising for a social account of dreaming a rigorous theoretical view that progressively generates empirical hypotheses is lacking. The previously presented social theories are either limited in their scope to attachment relations or bond-strengthening functions, mindreading training or are arguably too vague as to generate testable predictions.

The first aim of this thesis is thus to formulate a more rigorous and covering *Social Simulation Theory of Dreaming* (SST). The second am is to carry out first empirical research on the specific hypotheses derived from SST—namely the *Sociality Bias,* the *Strengthening Hypothesis*, the *Practise and Preparation hypothesis*, and the *Compensation Hypothesis*—to estimate how waking life social events relate to our interpersonal dream world. For this a content analysis measure, the *Social Content Scale* is developed to specifically extract the various social features from narrative reports. Finally, to address a specific methodological concern of currently unfeasible accurate sleep parameter assessment outside of laboratory conditions, we attempt to validate a specific easy-to-use home sleep monitoring device.

6 Methods

The studies carried out as part of this doctoral dissertation were based on three different data sets, two of which were collected specifically for this purpose (Studies III & IV, and one making use of an existing dataset (Study II). The fourth manuscript (Study I) is a theoretical review, and thus reports no methods.

6.1 Participants

6.1.1 Study I

Study I consisted of a theoretical review and contained no participants.

6.1.2 Study II – The Harvard data

The first empirical test of SST was carried out using an existing dataset, collected in the 1990's at the Department of Psychiatry at Harvard Medical School in the United States. The dataset contained both wake and dream reports, with dream reports collected from both REM and NREM stages throughout the night. The full dataset consisted of oral reports collected over a fortnight from 16 undergraduates (8 women, age range 19–26) (Stickgold et al., 2001).

6.1.3 Study III – The Seili data

The second empirical test of the SST was based on a dataset collected at the University of Turku, Finland. Participant recruitment was carried out through university mailing lists and reached students, staff, and alumni. Altogether 27 participants completed the online recruitment process, consisting of the Pittsburgh Sleep Quality Index (Buysse et al., 1989) and general questions about interest in dreams. Participants were approached based on their PSQI scores matched by gender. Participants who reported existing neurological or psychiatric diagnoses as part of the PSQI were excluded from the study.

Twenty participants were selected to take part in the study, with two participants cancelling their participation on the morning before the experimental condition, leaving the total sample size at 18 (13 women, $M_{age} = 30.17$ $SD_{age} = 8.29$, age range = 19–54). The sample size was limited by feasibility and resource limitations (see section 6.2.2).

6.1.4 Study IV – The Sleep laboratory data

The third dataset's participants were recruited through the University of Turku mailing lists. Similarly to Study III, the participants were selected based on an online PSQI screening, excluding spousal questions. Exclusion criteria were a PSQI score > 5 or a reported history of neurological or psychiatric diagnoses. However, one participant was included in the sample despite reporting a PSQI score of 6, following an individual interview suggesting applicability.[38] The final sleep laboratory sample consisted of ten right-handed non-smoking participants (5 women, $M_{age} = 24.5$, $SD_{age} = 2.51$), age range 18–30 years, with a $BMI < 30\ kg/m^2$, and was limited by feasibility concerns.

6.2 Procedure

6.2.1 Study II

The undergraduates took part in a two-week study, where they provided both daily dream and wake reports. On half of the nights, the participants were awoken both from early- and late-night sleep, while the other reports were collected from spontaneous awakenings (Stickgold et al., 1998). The REM/NREM differentiation was based on the *Nightcap* sleep-monitor assessment (Ajilore et al., 1995). The wake reports were collected using the experience sampling method (ESM), with participants prompted four times a day to report their most recent activity into a tape recorder.

A representative subsample consisting of 232 dictated dream and 232 wake reports were selected from the original larger sample before content analysis coding of the reports. The dream report sample was selected based on the number of reports per participant, report length, time of awakening, gender, and the even ratio between NREM and REM reports. The wake sample was matched by the number of reports per subject and report length, evenly chosen from each of the four prompting intervals. The final sample was data from 15 participants, eight of whom were female. Reports shorter than 30 words were excluded, and the reports were randomized by a person

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[38] The high PSQI score was due to daytime sleepiness, which was not considered to warrant exclusion from this study.

external to the content analysis process. At this stage the dream reports were provided to the independent judges. During the content analysis stage, one REM dream report had to be eliminated due to its meaningful word count being below 30 words. Altogether 232 wake, and 231 dream reports—115 REM and 116 NREM—were thus analysed. Wake reports were on average 107.82 (*SD* = 51.15, *range* = 45.5–153.91) words long, REM reports were on average 170.70 (*SD* = 208.0, range = 31–1719) words long, and NREM reports 104.50 (*SD* = 104.10, range = 30–625) words long. REM reports were longer than wake and NREM reports ($p < .0001$).

6.2.2 Study III

The study took place in two three-week periods with nine participants each in a similar setting. The experimental part consisted of a five-day island retreat, where the participants spent three-days in voluntary social isolation, without social interaction nor access to phones, television nor the internet. Questionnaires related to well-being and social behaviour were collected both before and after the study period. The participants reported baseline reports on three nights before the seclusion retreat, with one non-reported night between baseline and the experimental condition. These reports were used both as a baseline and to ensure the participants could follow the dream reporting procedure. Questionnaires, and dream and mind wandering reports, were collected online via Webropol-questionnaires (www.webropol-surveys.com). Participants were provided written instructions on how to accurately report their dreams, also in printed form during the seclusion period. The online platform prompted the participants to report their dream as accurately and truthfully as possible one dream at a time. Additionally, each dream report was appended with questions on the approximate number of social interactions the participants had experienced throughout preceding day and they also self-assessed the emotional tone of the dream (published in Sikka et al., 2021).

The seclusion retreat began on Monday and participants were shipped to a university research facility on the remote island of Seili in the Turku archipelago. The participants stayed in single rooms for four nights. Additionally, two researchers were present to carry out the practical tasks of the experiment and function as emergency contact persons. As the study took place in late September (group 1) and early October (group 2), there were only a few other people on the island, including restaurant and maintenance personnel.

Throughout the three-day isolation period, the participants were instructed to avoid social contact and their laptops and online devices were collected for safe keeping. In addition to these instructions, the participants' activities on the island were not limited. Food was delivered thrice a day without social contact, and any needs, worries, and requests were communicated via a notebook. During seclusion, the participants did not have access to the online questionnaires and used a pen-and-paper method of collecting the reports, which were then transcribed by themselves to the online questionnaire following return from the retreat (with notebooks returned to the researchers).

Sleep parameters were measured by ZEO sleep monitor devices (see Chapter 3.2.3). ZEO devices were used throughout the retreat, and for the five additional nights at home following the retreat period. The sleep measures collected were total sleep time, amount of REM, light and deep sleep, the number of awakenings, and sleep onset latency (SOL). Additionally, percentages of REM and deep sleep from total sleep time were calculated. On Friday morning the seclusion period was ended, the participants filled a brief questionnaire about their experiences and following a communal debrief the participants were returned to mainland. Following the retreat, they continued to collect dream reports for five days, included as post-seclusion reports.

6.2.3 Study IV

Participants in the Beddit sleep tracker (BST) home sleep monitor validation study slept two non-consecutive nights within one week at the University of Turku Sleep Research Centre sleep laboratory. The use of either alcohol and/or medication was prohibited for the preceding day, as well as caffeine for 6 hours before the laboratory night. Simultaneous recordings were collected from an Embla PSG device (6 electrodes: C3–A2, C4–A1, O1–A2, O2–A1, F3–A2, F4–A1, Cz as Ref; EKG1&2; EOG1&2; EMG1&2; oximetry; thorax & abdomen belts), the BST, as well as the Interaxon Muse headband (data not available due to collection and transformation issues). The sleep laboratory bed was fitted with the BST sensor under the mattress topper and connected to an Android tablet device in the observation room via Bluetooth[39]. The recording was manually synchronized to begin simultaneously across devices. Additionally, before and after both nights, participants answered a subjective well-being questionnaire for an adjacent study.

6.3 Content analysis and sleep assessment

6.3.1 The Social Content Scale

The Social Content Scale (SCS) was designed to delineate various social situations from narrative reports in Studies II and III (see Study II supplement). The scoring

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[39] BST application 1.7.3 for the first ten collected nights, and 1.8.0. for the latter ten, due to an automatic product update.

procedure is carried out by two independent raters who identify social events from narrative reports, and then proceed towards a more specific categorization. This consists of logging the interacting participants, their gender and their numbers, followed with details on the social event itself: whether it is a passive or an active perception or an interaction (uni- or multilateral, or a joint action between the characters[40]), and what is its type and valence (positive, negative or neutral with specific subcategories). Finally, the event is categorized depending on whether it was experienced as happening in the past, present or future (for a flowchart, see Figure 1). Disagreements were resolved via a consensus discussion between the raters.

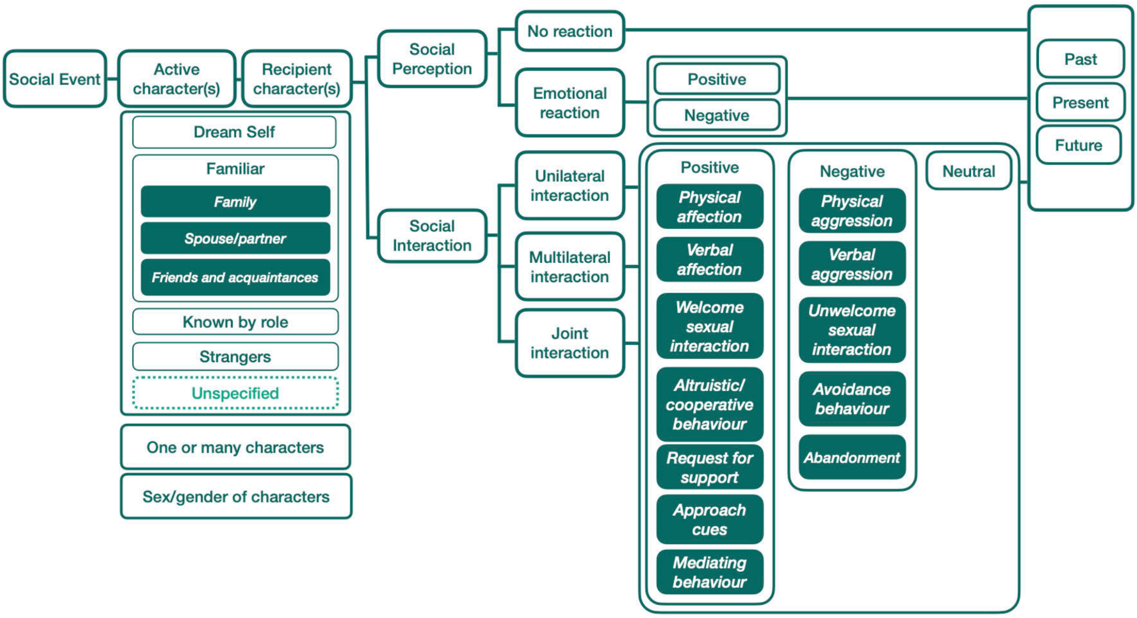

Figure 1. Flowchart of the Social Content Scale content analysis process.

6.3.2 Sleep assessment

PSG data for sleep parameters were analysed in 30 second epochs by an experienced sleep technician using the Rem-Logic program and following the American

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[40] *Unilateral* here refers to a situation where a perception of a character causes another to intentionally act in response (for example, shouting out at a person upon seeing another character), *multilateral* to a situation where there is an interaction simulation where characters respond to each other's behaviours (for example, character asks for coffee and the other provides it), and *joint interaction* to instances where the characters act together (for example, upon a shared goal or engage in discussion).

Academy of Sleep Medicine (AASM) guidelines (Iber et al., 2007). The automatically calculated BST total amount of sleep was compared with PSG total sleep time, BST "time to fall asleep" to PSG SOL, and BST' WASO and SE to their corresponding PSG categories. BST data was manually categorized to sleep stages from the data graphs it provides. BST provides two-minute data segments in the form of a graphical presentation of sleep on an axis of deep sleep–light sleep[41]. These BST data were first transformed into 30-second epochs, and then compared to the corresponding PSG epochs. To achieve this, the BST hypnogram was recoded to four corresponding PSG stages without stage REM (wake = wake; light sleep = N1 and N2 sleep with cutoff calculated from midpoint of the light sleep category in the BST hypnogram; deep sleep = N3 sleep). If the BST sleep stage score changed within the 2 minutes, the first minute was scored as the preceding and the latter minute as the following sleep stage.

6.3.3 Questionnaire measures

6.3.3.1 Patient health questionnaire

The Finnish version of the Patient Health Questionnaire (PHQ-9; Kroenke & Spitzer, 2002) was used in Study III to assess the presence of depressive symptoms. PHQ-9 is a brief 9-item self-report questionnaire, explicitly based on the diagnostic criteria for major depressive disorder as outlined in the 4th edition of the Diagnostic and statistical manual of mental disorders' (DSM-IV, American Psychiatric Association, 1994). Consequently, the PHQ-9 is considered a reliable way to assess depression and has adequate psychometric properties (Cameron et al., 2008; Titov et al., 2011). Participants respond to items on a 4-point Likert scale ranging from 0 (Not at all) to 4 (Nearly every day). A score of 10 or greater from the maximum of 24 is considered as indicative of the presence of major depressive disorder. The internal reliability (Cronbach's alpha) of the PHQ-9 total score in Study III was $\alpha = .73$, *95% CI* [0.55, 0.90].

6.3.3.2 Reflective functioning questionnaire

Th participants' ability to mentalize, i.e., their *reflective capacity*, was assessed using the Finnish version of the brief 8-item Reflective Functioning Questionnaire (RFQ; Fonagy et al., 2016). RFQ consists of short claims (e.g., 'Sometimes I do things

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[41] Automated BST scoring of REM sleep, while available in an earlier version and used in the pilot, was no longer available in the final data collection phase due to an app update.

without really knowing why'), to which participants respond on a 7-point Likert scale from 1 (Strongly disagree) to 7 (Strongly agree). The RFQ scoring system transforms the scores to vary between 0 and 3 (Fonagy et al., 2016). The scale has a two-factorial structure. It assesses both the certainty (RFQ_C) and the uncertainty about mental states of self and others (RFQ_U). The factors differ in their aims: RFQ_C is related to attachment security and non-suicidal types of self-harm, whereas RFQ_U predicts more persistent psychopathology, especially borderline personality disorder (BPD), and severe problems of mentalizing (Badoud et al., 2015; Fonagy et al., 2016). In Study III the RFQ_C factor was used, as we excluded participants with psychiatric diagnoses in the participant selection phase. The internal reliability (Cronbach's alpha) of the RFQ_C score in Study III was $\alpha = .68$, *95% CI* [0.45, 0.91].

6.3.3.3 Need to belong

The individual's belongingness to a group was assessed using the back-translated Finnish version of the Need to Belong questionnaire (NTB; Baumeister & Leary, 1995). NTB includes short claims (e.g., 'I want other people to accept me'), to which participants respond on a 5-point Likert scale, ranging from 1 (not at all) to 5 (extremely). The individual scores produce a sum score ranging between 10 and 50 points, where a higher score indicates a stronger need to belong. In Study III the internal reliability (Cronbach's alpha) of the NTB total score was $\alpha = .86$, *95% CI* [0.77, 0.96].

6.3.4 Statistical analyses

The three empirical studies varied in their choice of statistical analyses and statistical programs.

6.3.4.1 Study II

In Study II the Mann-Whitney (U) -test was first used to compare the number and length of reports from each condition, and the number of social events across sexes. Next, Wilcoxon signed rank (Z) -test was used to compare the more specific report contents across the time of night, sleep/wake stages, and the numbers of neutral, positive, and negative interactions. Friedman's (χ^2) test was used to compare the number of social interactions in early and late NREM and REM dreams, specifically. The reports were controlled for report length effects by calculating the average number of events, perceptions, and interactions for every 100 words. For nominal variables, cross tabulation and Pearson's ($\chi 2$) test were used, with either Odds Ratios

(*OR*), or Cohens *d* (transformed from $\chi 2$- and *Z*-scores) used as effect size estimates (e.g., Rosenthal & DiMatteo, 2001). In situations where Pearson's $\chi 2$-tests' degrees of freedom exceeded 1 the effect size estimate of choice was Cramer's *V*.

Furthermore, to evaluate the relationship between the number of social interactions and the report condition, a generalized linear mixed model (GLMM) was built using the lme4 package (Bates et al., 2015) for R. This allows control of the variance caused by the nestedness of the reports within the data. In other words, it allows for the assessment of whether individual differences account for the found effects. This was carried out binomially on the level of dream and wake reports. The fixed effects were (i) presence of social interaction, and (ii) the report state (dream or wake). The random effects were (iii) subject and (iv) gender (e.g., Baayen et al., 2008). For additional verification, two competing models with and without subject as a fixed effect were built, and analysed using analysis of variance (ANOVA) (Bolker et al., 2009; Pinheiro & Bates, 2000).

6.3.4.2 Study III

Data from Study III were analysed using linear mixed-effects models (LMM) using the lme4 package (Bates et al., 2015) in the R statistical software (Version 3.6.2). The analysis were carried out as separate models for i) the number of dream social interactions, ii) number of strangers and known characters in dream interactions, iii) number of positive and iv) negative interactions in dreams, and v) the amount of REM sleep (as a proportion of total sleep time). The *Sociality Bias* was in this study operationalized as a *sociality bias ratio*, arrived at by dividing the number of dream interactions (transformed to a 5-point scale corresponding to the daily wake estimate: 0 interactions = 1; 1–5 interactions = 2, 6–15 interactions = 3, 16–25 interactions = 4, and more than 25 = 5) with the number of wake interactions of the preceding day. Thus, the lower the bias score (<1) the less frequent interactions in dreams are compared to the preceding day. It should be noted that this differs from the *Sociality Bias* as estimated in Study II, as this compares the social interactions from the totality of the preceding day, and not only corresponding waking instances. In essence, it estimates what is the ratio between one dream sociality with that of the whole preceding day.

A logarithmic transformation was performed to the sociality bias ratio prior to the analyses due to a skewed distribution. The models were built with condition (pre-seclusion vs. seclusion vs. post-seclusion) added as a successive difference contrast coded fixed effects variable. The exception is the REM sleep model, where location was added as treatment coded fixed effects variable (post-seclusion was set as baseline).[42] Finally, PHQ-9, RFQ_C, and NTB scores were added to all dream content models as centred fixed effects variables. The correlation between measures was modest and ranged from .21 to .43. Only the main effect of the fixed effects variables was analysed. Participants were fitted as random effects, with location added as by-participant random slope. In instances where the model failed to converge, a trimming procedure was performed on the random structure by removing the correlation between the intercept and the slope (Brauer & Curtin, 2018).

6.3.4.3 Study IV

Statistical analyses for Study IV were performed using the IBM SPSS Statistics (version 22), with the significance level preset to $p < .05$. Normality assumptions were tested using Kolmogorov-Smirnov test. Paired samples *t* tests were used for normally distributed variables, and Mann-Whitney *U* test for non-normally distributed variables. Cohen kappa coefficient was used to evaluate the correspondence between sleep stage scoring from PSG and BST.

One night of data was omitted from the analyses, as BST had lost wireless connection to the tablet for an unknown reason. Additionally, BST failed to provide complete data for two nights: SOL was missing from one night, and another lacked SOL, WASO and SE. These, and their corresponding PSG data, were omitted from the comparisons.

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[42] As noted in the earlier chapter, REM sleep was not collected in pre-seclusion baseline.

7 Results

7.1 A brief review of theoretical Study I

In Study I we formulated the first outlines of the SST. Similarly to the Introduction of this thesis the world-simulation view of dreaming was evaluated and considered to form a robust background assumption on which to construct the more specific theory. Following this, previous work and findings on the social content of dreams, as well as evolutionary, and social and developmental psychological literature were reviewed. From this basis the specific hypotheses of SST were formulated. The most general hypothesis of SST is that dreams are:

> "specialized in simulating the most important social connections and networks of the dreamer to give an additional selective advantage and to enhance the survival of the dreamer in waking life" (Study I p. 21).

In more detail the main hypotheses proposed are:

1. *Sociality Bias:* Social interactions should appear more frequently in dream life than in a corresponding stretch of waking life
2. *Exaggeration Hypothesis*: Strangers or unfamiliar people should be overrepresented in dreams as compared to waking life, to simulate and rehearse perceptual categorization (familiar vs. unfamiliar)
3. *Strengthening Hypothesis:* The function of social simulations in dreams is to maintain and strengthen the dreamer's most important social bonds from waking life.
4. *Practise and Preparation Hypothesis*: The function of social simulations in dreams is to force the dreamer *to practise important social bonding skills*, such as how to give social support to others.
5. *Mindreading hypothesis*: Dreaming specifically simulates mindreading or mentalizing abilities

Following the publication of Study 1, an additional hypothesis was formulated (Tuominen et al., 2019):

6. *The Compensation Hypothesis*: When social interactions in waking are radically reduced dreams begin to compensate by generating more social simulations to ensure group inclusion.

7.2 Are dreams more social than waking life?

Studies II and III aimed to answer the questions presented in Study I that lie at the heart of SST. First of these is the question of Sociality Bias, i.e., whether dreams are more social than corresponding waking life. In Study II a comparison between corresponding wake and dream reports was carried out, whereas in Study III the number of social interactions was experimentally controlled by the social seclusion condition. Study II found dreams to be more social than waking life ($p < .05$, $OR = 2.88$, *95% CI* [1.86, 4.47]). At least one social situation was present in 83.5% of dream reports, while this was the case only in 63.8% of waking reports. Social content was primarily in the form of social interaction in both wake and dream reports, with 84.7% (166/197) of waking, and 70.7% (290/410) of dream social situations categorized as interactions. Waking life social situations were thus weighted more toward interactions than dream social situations ($p < .05$, $OR = 0.44$, *95% CI* [0.28, 0.68]). Additional generalized linear mixed models verified that these findings were not due to subject or report level variation.

In Study III waking social interactions were experimentally controlled, and contrarily to Study II were not assessed via wake reports, but via an amalgamated number of social interactions from the whole preceding day, self-reported by the participant. Throughout the whole dream report dataset there were 303 dream reports, of which 95.4% (289) contained social content, the majority (93.8%) of which was categorized as social interaction. There were on the average 5.8 social events and 4.4 social interactions reported per dream, with slightly fewer ($M = 3.9$, $SD = 3.67$) interactions reported during the seclusion than the in the pre- and post-seclusion dream reports ($M = 4.64$, $SD = 4.10$; $M = 4.8$, $SD = 5.52$, respectively). During the three-day social seclusion only three dream reports failed to contain any social situations, all derived from a single participant. Linear mixed-effects model (LMM) was built for the *Sociality Bias*, operationalized as the ratio of wake and dream social interactions. The results indicated the seclusion dream reports to be more social than the preceding baseline reports ($\beta = 1.03$, *95% CI* [0.91, 1.15], $t = 17.09$), as well as the subsequent post-seclusion reports ($\beta = 1.09$, *95% CI* [1.20, 0.98], $t = 19.20$) (See Figure 2). The number of social interactions in dreams were thus revealed to be relatively stable and not modulated by changes in the actual number of social situations in the waking social environment.

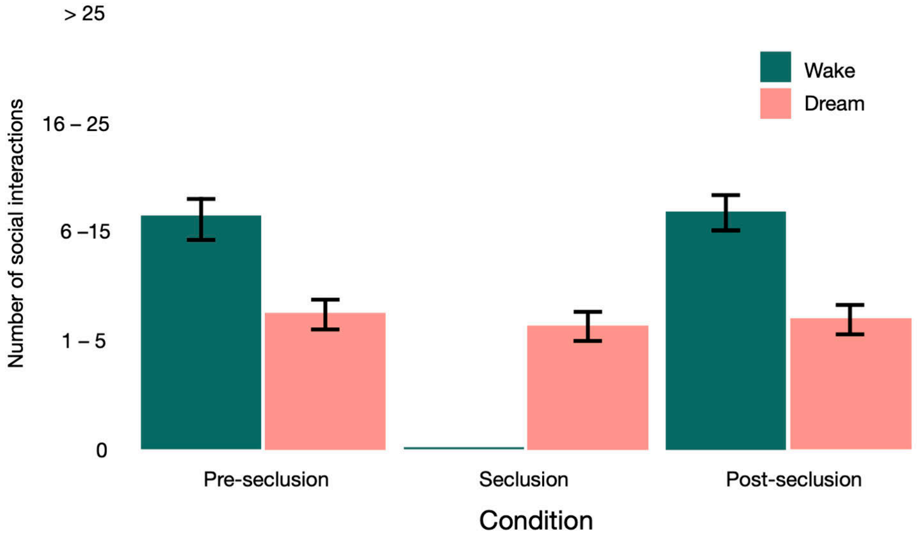

Figure 2. Number of social interactions during pre-seclusion baseline, seclusion and post-seclusion. Wake interactions are based on a self-estimate of the totality of social interactions during the preceding day, whereas dream interactions are based on dream report content analysis. Error bars represent 95% confidence intervals.

7.3 Do social interactions differ in quality of content between wake and dream states?

Study II compared wake reports with NREM and REM reports collected throughout the night, thus allowing for a comparison between early and late reports from both REM and NREM sleep stages. Of the social situations nearly twice as many were social perception in both REM (29.6%) and NREM (28.2%) dream reports compared to waking life (15.3%). The subgroup of this category consisted of social perception that evokes an emotional reaction. This was present in 5.1% of REM, but only 2.5% of NREM, and 2% in wake report social situations. Social interaction was categorized into unilateral, i.e., an interaction where only one participant was active (REM = 27.5%, NREM = 35.7%, Wake = 19.9%), multilateral, i.e., interactions where all participants were active (REM = 65.7%, NREM = 56.3%, Wake = 71.1%), and joint, i.e., where the participants acted together on a shared task (REM = 6.7%, NREM = 8.9%, Wake = 8.4%).

Neutral interaction was the most frequent coded category in both dream (67.2%) and wake (75.9%) reports. Interactions were coded as positive in 21.7% of dream and 19.8% of wake reports, whereas the interaction category was negative in 11% of dream and 4.2% of wake reports. Following the control for report length by dividing the number of social interactions per 100 words, negative interactions were found to be more frequent in dreams than in waking life (*Z* = −2.134, *p* = .033, *d* = 0.90). See Table 1 for a concise comparison of these frequencies between Studies II and III.

Table 1. Comparison of social content in Studies II and III.

	Study II		**Study III**		
	Wake	**Dream**	**Pre**	**Seclusion**	**Post**
Measure			% Soc Events	% Soc Events	% Soc Events
Social Interactions	70.7%	84.7%	74.4%	75.3%	78.2%
Neutral	75.9%	67.2%	68.3%	64.6%	63.0%
Positive	19.9%	21.6%	20.2%	21.6%	20.1%
physical affection*	3.0%	3.2%	3.4%	2.9%	3.4%
verbal affection*	6.1%	12.7%	10.2%	7.4%	4.2%
welcome sexual interaction*	0%	3.2%	13.6%	2.9%	11.8%
cooperative or altruistic behavior*	63.6%	55.6%	44.3%	54.4%	41.2%
approach cues*	9.1%	6.3%	10.2%	11.8%	13.4%
request for support*	15.2%	9.5%	12.5%	16.2%	20.2%
mediating behavior*	3.0%	9.5%	5.7%	4.4%	5.9%
Negative	4.21%	11%	11.5%	13.9%	16.1%
physical aggression*	14.2%	15.6%	18%	20.5%	30.4%
verbal aggression*	28.6%	34.4%	26%	31.8%	23.9%
forcing, obstructing*	0%	12.5%	4.0%	0%	5.4%
unwelcome sexual interaction*	0%	3.1%	2.0%	0%	0%
avoidance behavior*	0%	9.4%	20.0%	13.6%	22.8%
abandonment, rejection*	57.1%	25%	30.0%	34.1%	17.4%
Interactions Familiar	91.8%	70.3%	70.2%	81.6%	77.9%
Interactions/Strangers**	8.1%	29.7%	81.4%	67.1%	78.6%

** Study II includes interactions with strangers only, whereas for Study III also includes interactions where strangers occur with familiar characters.

There were no differences in comparisons between REM and NREM report contents in positive and neutral (*p* > .05, *OR* = 0.71 *95% CI* [0.40, 1.26]), and negative and neutral interactions (*p* > .05, *OR* = 0.73 *95% CI* [0.34, 1.56]). Furthermore, when subdividing the dream reports by time of night there were no differences between the early and late REM and NREM reports between the different types of interactions (*χ2* (6, N = 290) = 3.14, *p* = .79, *V* = 0.79). (See Table 2)

Table 2. Wake interactions are based on a self-estimate of the totality of social interactions during the preceding day, whereas dream interactions are based on dream report content analysis. Error bars represent 95% confidence intervals.

	Time of night					
	All REM (n = 177) n /%	Early REM (n = 78) n /%	Late REM (n = 99) n /%	All NREM (n = 113) n /%	Early NREM (n = 46) n /%	Late NREM (n = 67) n /%
Positive	35 / 19.8	14 / 17.9	21 / 21.2	28 / 24.8	11 / 23.9	17 / 25.4
Negative	18 / 10.2	8 / 10.3	10 / 10.1	14 / 12.4	4 / 8.7	10 / 14.9
Neutral	125/ 70.1	56 / 71.8	68 / 68.7	71 / 62.8	31 / 67.4	40 / 59.7

In Study III social interactions in the waking state were experimentally controlled via the social seclusion setting. The most common interaction type was neutral, accounting for 63.0–68.3% of dreamt social interactions throughout the whole study period. Similarly to Study II, the second most common interaction type was positive (pre = 20.2%, seclusion = 21.6%, post = 20.1%) (See Figure 3). However, there were no effects on the model on the number of positive interactions in dreams. The model on the *number of negative interactions in dreams* showed a main effect for the reflective functioning RFQ_C subscale. An increase in the RFQ_C score corresponds to an increase in the number of negative interactions in dream reports, $\beta = 0.36$, *95% CI* [0.14, 0.58], $z = 3.16$.

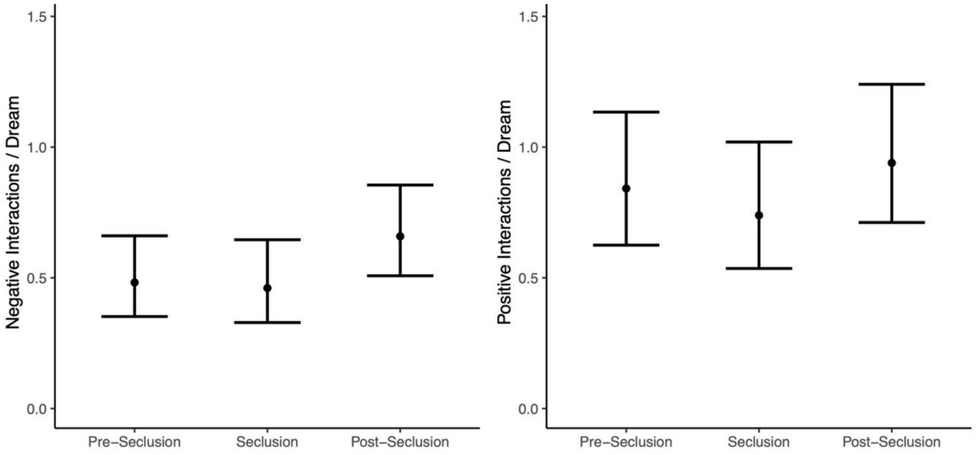

Figure 3. Number of negative and positive interactions per dream during pre-seclusion, seclusion and post-seclusion.

7.4 Do dreams strengthen close relationships?

To test the Strengthening hypothesis as outlined in Study I, we compared the quality of social interactions between familiar characters and strangers in both Study II and Study III. In Study II the self was the involved in 84.8% of dream social interactions, of which the self was coded as the initiating character in 72% of interactions. Considering only the positive or negative interactions with either personally known characters or other characters, no statistically significant difference was found in interaction quality neither in dream ($\chi 2$ (1, N = 73) = 1.81, p = .18, d = 0.32) nor wake reports ($\chi 2$ (1, N = 35) = 0.42, p = .52, d = 0.22). Dream and wake self's positive and negative interactions with familiar vs. unknown persons just failed to reach the level of statistical significance ($\chi 2$ (1, N = 108) = 3.79, p=.052, d = 0.38). Percentages for positive, negative and neutral interactions per character type are available in Table 3.

Table 3. Quality of self's interactions by interaction partner in dream and wake reports in Study II.

Quality of interaction	**Familiar characters n /%**		**Strangers n /%**	
	Dream	Wake	Dream	Wake
Positive	34 / 19.7	28 / 19.0	17 / 23.3	5 / 38.4
Negative	11 / 6.4	4 / 2.7	11 / 15.1	1 / 7.7
Neutral	128 / 74.0	115 / 78.2	45 / 61.6	7 / 53.8
Total	**173 / 100**	**147 / 100**	**73 / 100**	**13 / 100**

In Study III the model found a lower likelihood of strangers in dreams during seclusion (67.1%) than in the pre-seclusion (81.4%) condition ($\beta = -0.29$, *95% CI* [-0.55, -0.02], $z = -2.10$), yet there was no effect between seclusion and post-seclusion (78.6%) reports ($\beta = 0.22$, *95% CI* [-0.04, 0.47], $z = 1.65$). Percentagewise there were more family members in dream reports during seclusion (37.2%) than in the pre- (24.8%) or post-seclusion reports (29.2%), less spousal dreams (5.8% v. 9.5% v. 10.3%) and fewer friends (57% v. 65.7% v. 60.4%). Overall dreams during seclusion contained more familiar (81.6%) characters than pre (70.2%) or post-seclusion (77.9%) reports, yet the model evidenced no effect for pre- ($\beta = 0.58$, *95% CI* [-0.27, 1.43], $z = 1.33$) or post-seclusion comparisons ($\beta = 0.22$, *95% CI* [-0.97, 0.54], $z = -0.56$) (see Figure 4).

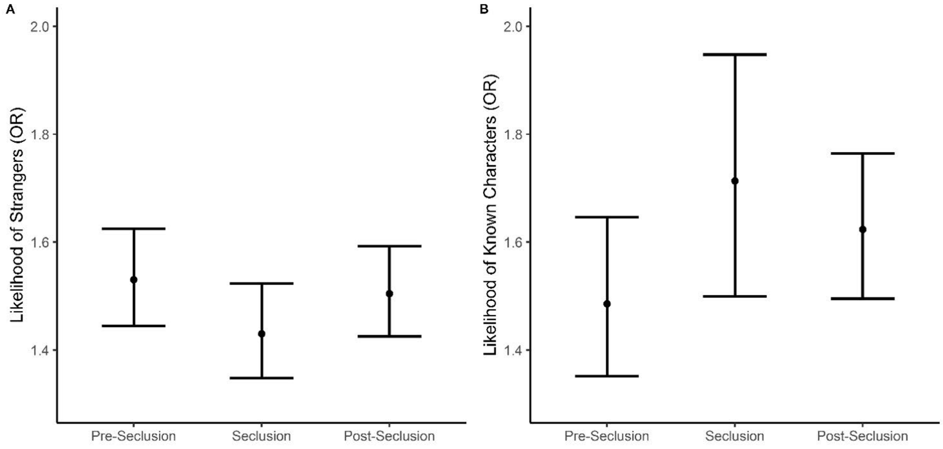

Figure 4. Likelihoods for strangers and familiar characters in dreams during pre-seclusion, seclusion and post-seclusion conditions.

7.5 The effect of social seclusion on REM sleep

Study III attempted to support an earlier study by Wood (1962), that found social exclusion to be accompanied by an increase in REM sleep on subsequent nights. Two observations had to be removed due to recording failure. Data was only collected during and after the seclusion retreat. Overall, total sleep time during the retreat was 409 (*SD* = 86) minutes, whereas following the retreat it was slightly less, at 402 (*SD* = 98) minutes. There was a main effect for increased REM during the seclusion (*M* = 31%, *SD* = 6%), compared to the post-seclusion data ($\beta = 0.03$, *95% CI* [0.01, 0.05], $t = 2.95$).

7.6 Validity of a ballistocardiograph-based home-monitoring system for sleep parameters

In Study IV we attempted to validate a ballistocardiograph home sleep monitoring device, the BST. According to the paired-samples *t* test, BST appears to incorrectly classify wakeful rest as sleep and thus overestimate total sleep time, resulting in a difference between the BST and PSG classifications ($t = 44.17$, $p < .01$). While there were no differences found in SOL ($Z = -1.14$, $p = .20$), WASO ($Z = -3.72$, $p < .01$) and SE ($Z = -3.34$, $p < .01$) both differed between PSG and BST. The difference in SE was not explained only by the tendency of BST to underestimate the amount of wake after sleep onset and the resulting overestimation of SE (see Figure 5, corresponding Bland-Altman plots in Study IV supplement).

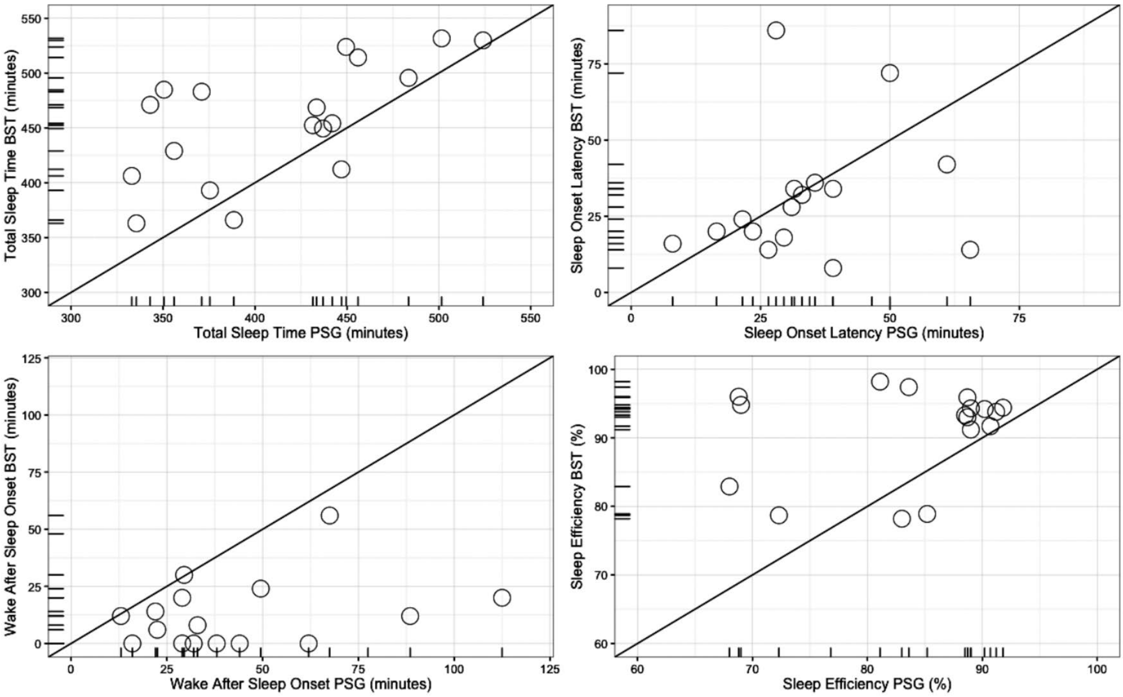

Figure 5. Comparisons of Beddit Sleep Tracker (BST) and polysomnography (PSG) sleep parameter estimations.

7.7 Can we use a ballistocardiograph to reliably differentiate between sleep stages?

Additionally, the applicability of BST for sleep stage classification was estimated. As noted previously, in the pilot stage of the study, BST provided a sleep stage classification, only to have this feature dropped before the laboratory measurements took place. In short, the stage REM as assessed by PSG was classified by BST as 6.1% wake, 30.4% as N1, 24.8% as N2, and 38.7% as N3 sleep (from a total of 3406 REM epochs). Thus, as PSG-scored REM sleep failed to correlate with any particular BST stage, REM sleep data points were dropped from the following analyses based on the PSG data (resulting in a total of 14900 remaining epochs).

Agreement between BST and PSG for the wake and NREM classifications was extremely poor (*kappa* = .095, *p* < .001), with mean inter-device Cohen kappa of .098 (*standard error* = .015, *range* = −.009 to .192, *95% CI* [.068, .129]). This lack of consensus motivated an additional simplification of data to the original, coarser BST classification of wake, light sleep (PSG stages N1 and N2 sleep) and deep sleep (PSG stage N3 sleep). This resulted in a slight improvement in agreement, yet remained very low (*kappa* = .101, *p* < .001). Further inter-device analyses resulted in mean kappa of .113 with mean standard error of .020 (*range* = .008 to .237, *95% CI* [.074, .152]).

8 Discussion

The aims of this thesis were to 1) review the social contents of dreams from a simulation viewpoint, 2) to elucidate a testable theory of social simulation in dreams, 3) to empirically assess the formulated hypotheses, and 4) to provide broader theoretical and methodological advances to dream research in particular, and ultimately consciousness research in general. To achieve this four studies were completed. In the theoretical Study I the social simulation theory of dreaming was developed based on an empirical review and theoretical considerations. This study formed the basis for Studies II and III that looked into some of the specific proposed hypotheses of SST using the novel SCS content analysis scale. These were the *Sociality Bias*; The *Strengthening Hypothesis*; the *Practice and Preparation Hypothesis*; and the *Compensation Hypothesis* (Tuominen & Valli, 2019). Simultaneously a replication of previous findings related to sleep structure and social content and/or environment were carried out. Finally, Study IV aimed to correct a methodological hindrance in dream research, by validating a ballistocardiograph-based home monitoring device for sleep tracking. While considerable ground to reach these objectives were covered, some remain unresolved and further questions have arisen. In this chapter I will attempt to address the state of the evidence for SST and consider the main findings in relation to the existing literature, critically evaluate the limitations, and, finally, consider the possible future outlooks and pathways for a more rigorous and unified understanding of dreaming.

8.1 Sociality Bias: Dreams are social simulations

As suggested by the *Sociality Bias* proposed in Study I dreams were found to be more social than corresponding waking life in both studies II and III. Whereas in Study II the comparisons were based on methodologically corresponding reports, in Study III the number of reported social interactions in a dream report was compared to the totality of social interactions in the preceding day. Here it should be noted that even with this method dreams appear remarkably social. This is at best a conservative estimate of the ratio between wake and dreaming, as the reporting procedure used narrows interactions with groups into a single interaction, whereas the self-report from daily activities differentiates such interactions into component individuals.[43] In Study II dreaming was found to be more social than corresponding waking life, thus replicating the previous finding of McNamara and colleagues (2005). Dream reports contained approximately 20% more social content than corresponding wake reports. In Study III the reported incidence of social situations was even higher, with over 95% of the dream reports containing at least one social situation, with over 4 interactions per dream on average.

Taking the findings from Studies II and III and considering the findings from previous research—for instance with the original study of McNamara and colleagues (2005) and the normative findings of the sociality of dreams in general (Domhoff, 1996; Domhoff & Schneider, 2018)—we can relatively safely state dreams to be biased toward social content in accordance with the predictions of SST. It seems that dream contents are not merely replays or similar in content to waking life, but actively select certain kinds of especially social experiences to be simulated.

8.2 The Strengthening Hypothesis: Dreams may strengthen most important social bonds

The *Strengthening Hypothesis* of SST states the function of social simulations to be the maintenance and strengthening of the dreamer's most important social bonds. Study II looked at whether specific kinds of experiences are simulated more often in interactions with familiar characters rather than strangers, yet failed to find a statistically significant effect. Overall Study II dreams contained more familiar (N=173) than unfamiliar character interactions (N=73), though this may be due to the fact that interactions that contained a familiar character were calculated as familiar—even if they also included strangers—to avoid double-counting. It thus seems that while positive interactions in dreams seem to be relatively as likely between familiar (19.7%) and unfamiliar (23.3%) dream characters, there is a bias toward negative interactions being more likely with strangers (6.4% v. 15.1%). NREM dreams were found to contain more friendly interactions (24.8%) than REM dreams (19.8%), but this difference disappeared after controlling for report length. There were no differences for time of night effects with regard to interaction quality.

In Study III the number of strangers in dreams decreased when people lacked social interactions in waking life. Before the seclusion 81.4% of interactions included at least one stranger, whereas during the seclusion this dropped to 67.1%. Following the seclusion, the number of strangers slightly increased again to 78.6%

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[43] For example, a reported instance of debating the exact air-speed velocity of unladen swallows with five friends will be categorized on the SCS as a single interaction with multiple recipient characters, whereas in the waking self-report estimate it is likely counted as five interactions.

of all interactions. This trend was reversed for the familiar characters, with 70.2% at baseline, 81.6% during seclusion and finally 77.9% in the five-day period following the retreat. Despite this trend the latter model failed to detect a statistically significant effect. This change in frequency was most pronounced in the family category which increased from 24.8% to 37.2% moving from baseline to seclusion, and returning to 29.2% at post-seclusion. Simultaneously the number of interactions with friends and spouse or partner decreased. The family category was not entered into the model separately from the more general familiar character category, however.

In conclusion there seems to be a tendency toward increasing the number of familiar relationships—especially kin—in dreams at the expense of simulations with strangers when the real-life social relationships are perturbed, as predicted by SST. However, at baseline there does not seem to be a differential effect for especially simulating bond-strengthening interactions with close others any more than with strangers. In addition to the studies reported here, relationship maintenance was found in nearly a third of dream reports in a study by Eldridge and colleagues (2016), which is relatively close to the ~20% of positive interactions as accounted for here. As proposed in Study III taken together these findings could lead us to revise the *Strengthening Hypothesis* as a dynamic feature, reacting to external circumstances, and actively simulating close bonds only when they are not active or when they are threatened in waking life.

8.3 The Practise and Preparation Hypothesis: Dreams practice important social bonding skills

The *Practise and Preparation Hypothesis* proposes dreams to force the dreamer to practise important social bonding skills, such as how to give social support to others. These include tasks such as mind-reading or cooperation. While the findings on mindreading are still under preparation, there is some indication of specifically cooperative behaviour in studies II and III. In both studies cooperation or altruistic behaviour was the most commonly found positive interaction, accounting for 55.6% in Study II and 41.2–54.4% in Study III of all positive interactions. Requesting support also increased in 12.5% in baseline to 16.2% in seclusion and onward to 20.5% of positive interactions in post-seclusion reports. However, the number of instances at this level of detail is too small to draw any conclusive statements. Additionally, positive interactions were rehearsed with strangers in Study II slightly more (23.3%) than with familiar people (19.7%). Of note is the dynamics of sexual interactions in dreams. In Study II one percent of dreams were sexual in nature, of which one instance was unconsentful. In Study III at baseline consented sexual interaction accounted for 2.8%, but dropped to only 0.6% during seclusion, only to return to 2.5% at post-seclusion. There was only one instance of unconsented sexual interaction throughout Study I, reported at baseline. Of negative content themes physical or verbal aggression as well as abandonment and avoidance behaviours were most common in both studies II and III.

After the publication of Study I, Eldridge and colleagues (2016) published findings indicating complex social interaction rehearsal was present in a fifth of dreams. Complexity here refers not only preplaying future interactions but also attempting to anticipate the responses and mental state of the interaction partner. Furthermore, Selterman and colleagues (2012) found dream simulations with close others to affect the dreamers' experiences and mood on the following day. This indicates that dreams not only simulate interactions with close others, but these simulations also have a causal effect into the subsequent waking state.

If dreaming is to simulate mind-reading or mentalizing it should be noted that here, too, there may be a discrepancy between an *accurate* and *functionally useful* inference. Research seems to suggest that we are relatively limited at representing others overall, and their motivations and intentions especially. Here a more targeted research question would be in order to compare dreaming to waking mind-reading. This is important as beliefs about others carry behavioural consequences. There are existing interesting findings about, for example, the impact of in- or out-group status in understanding others. We may see dream simulations as an explicit method to hone our skill to understand the mind of the other. It is well known that we are liable for social projection, an egocentric heuristic where we overestimate others to share our view of the world, and this feature to be stronger in the in-group context (for a review and meta-analysis, see Robbins & Krueger, 2005).[44] This would provide an interesting research question on whether our perception of others (via, for example, factual or experiential information) is reflected in their dream appearances and whether this effect is differential for in- and out-group members.

In conclusion, the *Practise and Preparation Hypothesis* seems to gain some additional support from the Studies II and III, but more specific studies on the contents of practise and their subsequent effects on waking behaviour are still required.

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[44] However, Bursztyn and colleagues (2020) found an opposite in-group effect. While a vast majority of young married Saudi-Arabian men privately announced support for women's participation in the labour market, they however similarly underestimate the amount of support from other men. When their misperceptions were corrected, they were more likely to turn their belief into behaviour, as measured by their wives' increased job-seeking.

8.4 The Compensation Hypothesis: Dreams do not compensate for social voluntary isolation

The *Compensation Hypothesis* was a later addition, based theoretically on the proposed way the sociometer (Anthony et al., 2007; Leary & Baumeister, 2000; Lin & Yuan-Yuan, 2009), an internal tracking measure of social inclusion and self-esteem, would interplay with the dream content selection (Study I; Tuominen et al., 2019). While the specific form of it relates to situations where inclusion into a group is in actuality threatened and there is a high risk of loneliness, we decided to test a particularly strong version of it in Study III. “Strong” here denotes that while the perceived and experienced social encounters were removed, there was no personal threat of actual exclusion.

Study III found the number of dream social interactions to remain relatively stable despite the removal of actual social wake interactions. While a remarkable finding for understanding the relationship between waking and dreaming, it did not support the compensation hypothesis as there was no increase in simulated social encounters in total. However, as noted previously, there was a change in interaction character type, with less strangers and more familiar people. It should be noted that in this sample the number of social simulations (95.4% of dream reports) was already higher than in Study II or in other previous research (Domhoff, 1996; Domhoff & Schneider, 2018).

Although it seems that the particularly strong version of the *Compensation Hypothesis* was not supported, given the social isolation and risk to close interpersonal relationships caused by the currently ongoing COVID-19 pandemic (Lieberoth et al., 2021; Yamada et al. 2021), these findings would seem to function as an important baseline for future research. In the case of COVID-19 the *Compensation Hypothesis* would face its proper test, and these data could give a specific effect for social isolation without (Study III) and with (COVID) actual fear of exclusion. In Study III no actual fear of exclusion was present and the isolation period of three days was relatively short. It seems that the proper test for this hypothesis is still to be carried out, yet could be achieved in the near future.

8.4.1 The role of REM and NREM in dream sociality is complicated

In Study II the differences between REM and NREM sleep social dream contents were compared, and when controlling for report length no differences were found between the two stages nor time of night (see below for a discussion on the validity and problems of such control). In Study III REM sleep was found to increase during the social seclusion, similarly to the findings of Wood (1962). While this points to a correlation between waking sociality and sleep the conclusions are still preliminary.

It seems to fit well with the McNamara's (1996) hypothesis that REM sleep dreams promote attachment functions and social bonding, especially as there were less strangers present in the corresponding dreams. However, it could also reflect some other feature entirely. For example, if NREM sleep is mainly for memory consolidation it can be argued that during restful isolation there are less requirements for memory consolidation than in a corresponding typical day, and thus there is less NREM sleep, here reported as the obverse. However, such a clear link seems to warrant future research in a more detailed and targeted fashion.

8.5 Critical remarks and shortcomings

In scientific work one should always aspire to criticism. It is built into the scientific enterprise, that one should do one's best to destroy one's own and others' hypotheses. This also applies to the SST. In what follows, I will go through the weak spots and concerns raised by myself or by other commentators, and will do my best to evaluate how damning these shortcomings are for SST. I explicitly take the viewpoint of SST, but most of these concerns are shared throughout the dream theories and methodologies. In addition to being critical I hope these will also prove both instructive and corrective.

8.5.1 Theoretical concerns

First, the obvious question would be whether the whole broader program of pinning down the function and essence of dreams is warranted. While I hope to have made my view clear on the broader aspect of this question in the previous chapters and the published manuscripts, some concerns still remain.

Similarly to most of our psychological research, dream research is a particularly Western project. This in the literature is known as the WEIRD problem—the acronym coming from the fact that a vast majority of our research on the mind stems from studying populations who are western, educated, industrialized, rich and democratic (Henrich et al., 2010). While there have been some interesting studies in non-western populations, such as in hunter-gatherers (for Yir-Yoront dreams see Domhoff, 1996; for Mehinaku dreams, see Gregor, 1981), in African cultures (for Nigerian dreams, see Ohaeri & Sunmola, 1994; for Ugandan dreams, see Johnson, 1978; for Zulu dreams see (Lee, 1954, 1958; Chidester, 2008) or in Asian cultures (for Japanese research see e.g. Griffith et al., 1958; Tartz & Krippner, 2017; Yamanaka et al., 1982; for Chinese research, see e.g. Yu, 2016; Yu & Shen, 2020), there is more variability in the data collection and underlying theoretical framework in such studies than in corresponding research in the USA, Canada or Europe.[45] However, it seems that the overall social quality of dreams seems to persist throughout cultures. Additionally, the presence of family members seems to be a common feature, with mother featuring most often even in dreams of people in patrilineal cultures. For example, in an Ugandan sample mother consisted of 11.9% of all non-self dream characters, whereas father accounted for 8.3% and friends for 7.1% (Johnson, 1978). Whether dreams simulate social situations in all humans or not is a key empirical question to be resolved. Do the specific hypotheses hold from hunter-gatherers to modern industrialized populations to nomadic groups or is there cultural variation? Given the evolutionary argument, social dreams should be ubiquitous and a theory to account for the specific social form it takes should have a way to deal with any possible cross-cultural differences without renegotiating the theoretical core.

8.5.2 Validity of the background assumptions

Another way to critically evaluate SST is to target the validity of the background assumptions on which it is built. While this includes the uses of evolutionary theory in general, and kin selection, indirect reciprocity and inclusive fitness in particular, as referred to in Study I, these issues are not considered here in further detail (see Chapter 4.1.3), as they constitute major debates within the biological sciences and would require a more extended treatment than is allowed here (see (Nowak & Sigmund, 2005; Park, 2007; Smith, 1964; Strassmann et al., 2011; Wade et al., 2010). Additionally, it should be noted that while the exact level of selection would change it would not bear on the veracity of SST, especially given that both kin selection and group selection share the same formalism, and only differ in the partition of the elements (Birch, 2017), or furthermore we reach the same evolutionary state by not only decreasing fecundity (i.e., the gene-centered approach) but also by decreasing the correlation of fecundity between replicating units (Koduri & Lo, 2021). Thus, we may end up at the same result using varied selection assumptions. However, the presented approaches in Study I are arguably the most commonly utilized and allow for comparison between various other phenomena.

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[45] These studies are often anthropological and take an explicit psychoanalytical view (Lincoln, 1935; Róheim, 1932; Seligman 1923). Eggan (1949, 1952) and Hall (1956) began a more descriptive collection of manifest dream contents, the former in Hopi indians and the latter in normative American population. The joint goal is to uncover the shared cross-cultural features of dreaming and thus either understand their function or understand the cultural influences.

8.5.2.1 Do dreams serve a biological function?

SST claims dreams to have been evolutionarily adaptive and increased the likelihood of survival and reproduction of the individual. This is a strong evolutionary argument, and aims to answer the question of *why* we dream. First, we can assess whether dreaming fulfils the hallmarks of an adaptation. While the arguments for the development of causal adaptive functions are untestable—human evolution being a one-shot occurrence—there are ways to assess the likelihood of whether a feature might be an adaptation or not (Tooby & Cosmides, 1992). Such *evolutionary functional analysis* of dreaming in general was carried out by Valli (2008) who found the probability of dreaming in general to be an adaptation relatively high. It is a recurring phenotypical characteristic constructed based on genetic instructions (Valli, 2008, p. 122). This is supported by findings that dreaming reliably develops in typical and stable environments, even in congenitally blind or paraplegic persons to share a specific kind of self-world model, despite it not corresponding to the actual state of affairs in reality. Whereas Valli assessed the EFA of the Threat simulation theory, here we should consider how SST would fit into this framework. Both of these theories can be grouped into a broader paradigm of world simulation theories that propose an evolutionary function for dreaming. Their explicit aim is to provide an overarching paradigm to account for dream simulations. However, while the Threat simulation theory can certainly be considered consistent with SST, we should also assess SST on its own merit. As such the question becomes why would social simulation be an adaptation? The short answer is that it has been likely to increase fitness by, for example, the rehearsal of social perception, interaction, social bonds and specific skills within the confines of sleep, where error and practice are of low cost and would translate into benefits in the waking. For example, practising interaction behaviours solely in the wake could carry adverse consequences either as risk of disruption of existing social ties or as failures in forming new ones. It should be noted that while dream sociality could have been an adaptation it may have lost its adaptive benefits over time. In this case SST would merely propose an arguably probable account for dream contents based on a consistent take on descriptive findings. However, here we have aimed at something further: Not only that dreams are an adaptation, but that they could still have adaptive benefits for the dreamer. That is that they result in subsequent changes in waking behaviour and/or attitudes in a way that increases social belonging, and have current fitness consequences. This is a risky proposal. As reviewed in Chapter 4.1.3. there is ample evidence for the evolutionary benefit for sociality overall, irrespective of whether the benefits are targeted at the level of the individual or the group, or both. Furthermore, these benefits are directly linked to waking well-being. Whether or not this proves to be the case for dreaming will require future research in varied settings and over time. With SST we hope to have provided a research program to mark a path to uncovering this issue.

Some researchers have argued that there is little direct benefit of such dream simulations and have questioned whether a functional explanation is necessary (see e.g., Domhoff & Schneider, 2018). They, however, conflate the psychological, immediate benefit for the dreamer with that of the fitness benefit. In short: Not *every* dream simulation need to carry a benefit for the subsequent day or even at all, but that overall the distributions of simulated contents are skewed toward the beneficial. In fact, if dreaming would be primarily for scenario rehearsal we should expect variation in content and in the success of dreamt behaviours and subsequent reactions (see below for an extended response). Furthermore, psychological well-being is not isomorphic with evolutionary benefit. For example, overall it may be beneficial to maintain or increase the social bonds with your kin, yet in some cases such relationships—or the consideration of such dreams in the waking state—may be ambivalent or even psychologically detrimental. It is therefore crucial to distinguish between the biological, psychological or other co-opted functions of dreams.

There remains the possibility that dreaming would not have been a direct adaptation itself, but an epiphenomenon of other features, later co-opted for an adaptive use. These spandrels interact and coexist with adaptive functions yet do not carry such functions themselves, even if in some instances they may be co-opted (Gould & Lewontin, 1979). One possibility for dream sociality is that it merely reflects the social aspects of our waking consciousness. This would, however, still leave the question of why we dream in the first place unanswered.

8.5.3 Does simulation in dreams really confer a benefit in waking performance?

If it were to be found dream experiences have no benefit for the waking life of an individual a biological function for dreams would seem unlikely. We have proposed that functional adaptations at this level of description could or even should have an effect on the waking state. Domhoff and Schneider (2018) have raised concerns on whether dreams in actuality do confer a benefit. Here I will address this concern but note, however, that lack of current utility does not necessarily imply lack of past utility due to, for example, an environmental mismatch.

The general idea of dreaming as a useful preparatory simulation has gained empirical support from human dream studies. In a study devised to test the Threat simulation theory, Arnulf and colleagues (2014) studied whether dreaming of a future stressful event—a medical school entry exam—affects subsequent performance. They found dreaming of the event on the preceding night, and the frequency of such dreams, to be correlated with better performance in the exam. These preparatory dreams were primarily about failing the examination. In an earlier example of this theme, Cohen and Cox (1975) subjected half of their participants to a stressful situation. They found that those participants who subsequently dreamt of the failure experience felt better about it and were more likely to retry the task. On the working-through emotion regulation literature Cartwright (1991, 1996) found depressed divorcees who dreamt more of their ex-spouse and children in an emotional manner better adapted to the new situation at one-year follow-up.

Additionally, literature suggests sleep to facilitate motor learning and thus enhances performance in as varied tasks as a ski simulator, visual discrimination, or finger tapping (Stickgold et al., 2000; Tucker, et al., 2011; Walker et al., 2002). Several studies have found REM sleep to increase in a linear fashion subsequent to learning previously unfamiliar tasks or situations (Fiss, 1990; Greenberg & Pearlman, 1993; Greenberg, Pillard & Pearlman, 1972; Lewin & Gombosh, 1972; Lucero, 1970). For example, an intensive foreign language course, students who had an increase in REM sleep evidenced enhanced performance compared to those whose REM remained at baseline levels (De Koninck et al., 1975, 1989; c.f. Meienberg, 1977). In a brain-imaging study on lucid dreaming, the dreamt motor activation elicited corresponding activation in the somatosensory cortex (Dresler et al., 2011). This suggests the overlap between motor imagery and motor execution to also be present in dreams, and thus provides a clue on how motor script rehearsal could affect future performance.[46] However, despite lucid dreaming sharing several of the features of REM sleep, it does differ in the availability of meta-cognitive access (i.e., the avatar is not oblivious) which marks the lucid state.

We have argued that dreams form an internal simulation, not unlike a flight simulator, that allows us to rehearse, try out and coordinate actions in a low-cost setting. This feature of simulating future scenarios and paths of action is similar to Tolman’s (1932, 1939) concept of vicarious trial-and-error, yet differs in its illusory depth: in dreams we are oblivious to the unreal nature of the experience and treat it as real.[47] To borrow a Shakespeare quote to underscore this further, you cannot:

> “…cloy the hungry edge of appetite. By bare imagination of a feast?” (Shakespeare, Rikhard II, Act 1, Scene 3)

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[46] Similar findings on the motor activity were measured from the throat of the zebra finch during sleep-time song reconfiguration (Young et al., 2017) which were discussed together with the rodent space cell findings in Chapter 2.3.2.1.1.

[47] Similar two-state memory system has been developed for artificial intelligence by the Deep Mind researchers in the form of deep Q-network (DQN), that has learned to outperform humans in various video games by storing a subset of the data and replaying it multiple times to infer the most appropriate action (Mnih et al., 2015; Hassabis et al., 2017).

8.5.3.1 Comparison with mental simulation in the waking state

Consider the use of mental training in the wake state could shed some of the doubt on the usefulness of mental simulation in dreams (in addition to the dream research overviewed in Chapter 2.2.2). In the arena of sports there is evidence for mental training as a performance enhancer. In the episodic simulation literature, several studies have looked into the effects of mental training on performance, ranging from increases in muscle strength (Yue & Cole, 1992) to better performance in sports (for a review see Kosslyn & Moulton, 2009; Moulton & Kosslyn, 2009). There seems to be a caveat, however. For better performance in, for example, simulated golf practice the simulation should be correct, for unsuccessful simulations weaken the actual subsequent performance by strengthening suboptimal motor or action scripts (Powell, 1973; Woolfolk, Parrish & Murphy, 1985). Furthermore, offline simulation is used in activities that go beyond mere simple motor actions (such as the correct golf swing) with good results, ranging from emergency scenario planning, wargaming or pilot training (see e.g., Prather, 1973). These complex scenarios rehearse higher order processes (decision-making, group coordination) in highly uncertain environments. In their meta-analysis Driskell, Copper and Moran (1994) found the benefits of mental practice to increase as a function of cognitive component complexity or size. In their assessment of SST Domhoff and Schneider (2018) refer to Ryals and Voss's (2015) review of the scope of implicit memory. This review, however explicitly answers most of the concerns (in their terms *beliefs*) posited by Domhoff and Schneider, such as the brief duration of implicit learning (for example, in recognition testing the effects are likely to last as long as explicit memory (Ryals & Voss, 2015, p. 53), and thus implicit memory is not necessarily only for short durations), its limited scope ("[implicit memory] …is far more broad and ubiquitous than is commonly appreciated", (Ryals & Voss, 2015 p. 54)). The overall conclusion from the literature is that our understanding of implicit memory is limited by the tasks used and questions posed, and that this should be borne in mind when discussing the possibilities or limits of implicit memory. It should also be considered that from a data-based bottom-up approach it seems that most of our psychological distinct concepts, such as working memory, do not necessarily factor neatly as such (see e.g., Eisenberg et al., 2019 using a multifaceted behavioral dataset to cluster various concepts using such approach).

8.6 Methodological concerns

Michel Jouvet gave a pessimistic view on the uses of methodology and the forward march of dream research, noting that every novel discovery since 1950's from REM sleep to muscle atonia, to dream bizarreness, could have been discovered centuries before by mere direct observation—i.e., if researchers had simply watched people sleep and collected their dream contents (Jouvet, 1992). What about the SST methodology? How does it fare with the problem of content analysis and rater accuracy raised by Sikka (2019)? While the broader questions to do with content analysis remain (see Chapter 3.1.2) it appears that social interactions are a more forgiving content to analyse than, for example, emotions, as they only have to deal with the normal retrospective reporting biases as mentioned below, but not with the additional problem of subjectivity of emotions. It is fairly easy to identify a social interaction, compared to identifying the emotional tone of a specific event. Still, the problem persists in smaller form, where the Social Content Scale deals with emotional reactions caused by dream characters, and their further classification into various positive or negative subcategories. Fortunately, this is an additional category in the scale to extend its coverage. In SST research we have included an additional question in the end of each report submission in the Webropol questionnaire, which asks the participant to rate the overall emotionality of the report on a five-point Likert scale for both positive and negative emotions separately. While this fails to answer the more specific emotional instances within those dream reports, it still allows us to compare the correspondence between waking and dreaming, and between specific conditions (see Sikka et al., 2021). The SCS seems to work as expected, with a high interrater-reliability and useful categories. As a hierarchical system, it also allows to choose the level of detail allowed by the sample size or question of interest. However, to better situate the findings from research using SCS within the broader dream research literature, its correspondence with the HvDC method should be carried out. This could also help clarify whether the differences in reference to the McNamara and colleagues' (2005) study on the nature of REM and NREM sleep are due to methodological or actual differences (for example the difference between the category of "negative interactions" of SCS and the "aggressive interactions" of HvDC tracking slightly different contents).

One methodological decision that directly bears on the findings of this thesis is to do with report length correction, which also should be considered, especially as this correction accounted for the difference between Study II and McNamara and colleagues' (2005) with regard to differential content simulation in sleep stages. In Study II we calculated the number of social interactions per 100 words. The rationale behind this was to be able to assess whether differences between sleep stages were due to the length of the report and not of the content itself, i.e., as REM sleep dreams are longer than NREM sleep dreams they are liable to have more content overall. As such, this control can be considered to give a density estimate. However, it can be argued that social interactions as such take more words to describe, or that unlike clear events (such as threats) they are more likely to take place as a background factor, and, thus, the use of this length control may result in losing valuable results. It has been argued that this control concentrates on the reporting practices more than on actual content (Hobson et al., 2000; Hunt et al., 1993). We considered the report length correction method to be a more cautious approach, as it was more likely to give a conservative estimate on the differences between sleep stages. However, since then new methods, such as graph analysis, have given new ways to approach this question (e.g., Martin et al., 2020). Given the problems in either correcting or not correcting for report length, the best option in the future would seem to be to report both measures and supplant these with graph theoretical analyses.

Additionally, in Study IV we hoped to increase the number of methodological tools for sleep measurement, with the aim of also helping us better understand the effect of sleep parameters on dream contents. Unfortunately, this task was unsuccessful, and BST was found to be poorly suited for any detailed sleep assessment. Fortunately, we were able to use the discontinued ZEO devices in Study III, but the problem of valid and feasible sleep collection devices still persists. Given that BST was acquired by Apple following our results it would seem that commercial interest in the topic remains, so one does remain hopeful.

8.7 Future of simulation theories of dreaming

Any topic as multifaceted as dreaming is very difficult to pin down under a single specific theoretical rubric. Such covering theories are relatively sparsely found within science and philosophy, and it is unlikely that a theory looking at a certain function—such as social function—of a specific mental state would count as a complete model for dreaming. Has this, then, been a futile endeavour? I remain optimistic and believe this not to be the case. Recently, dream research has converged on some views that our research has either validated or used. The next step on this slow march toward a covering, testable theory of dreaming would be to assess the strengths and weaknesses of each of the varying accounts of dreaming. One should then classify where they agree and disagree, where there are points of departure and where the theories are concerned with different levels of explanation. This taxonomy can then be used to formulate competing hypotheses derived from theoretical accounts, similarly to what has been attempted in the scope of this thesis. Based on this research one could begin to combine and reformulate a broader theory. In order for this to be actually achievable this project would require humility and lowering of hübris of the researchers to join forces and truly try to see how a complete theory of dreaming can be reached even at the risk of losing one's pet theories or favourite mechanisms. It is easy to unconsciously or consciously build strawmen or misunderstand the competing accounts, and to avoid this an open collaboration for the benefit of the topic and not for individuals would be required. Taking the first steps from an SST endeavour we could already see clear points of unification with several other theories. Most obviously of course SST could be combined with Threat simulation theory, as they already partially overlap within the area of social threatening content, and in the broader philosophical background assumptions. Argument over whether negative social content should support SST or the Threat simulation theory is of course nonsensical, as it would presuppose that the two are mutually exclusive and that either of the theories would be a complete account. While the specific hypotheses tested under this thesis have been to assess the predictions of SST, this end state of combining the threat and social simulation theories to a broad empirically testable theory is already explicitly noted in Study I. The results seem to suggest that when combined these theories would have great explanatory power and account for content in nearly all dreams.

Similarly, it would seem that predictive coding (PC) views of dreaming could coexist with SST and the Threat simulation theory with little modification. One such unifying move would be to consider the *a priori* weighting of the internal models. Whereas currently the predictive coding views argue the dream bias for social content to be due to the complexity of interpersonal models and the thus required prediction streamlining, one could also propose an evolutionary account: the most evolutionarily salient features of our environment should be overemphasized in the off-line model as the more accurate the predictions in such cases, the more likely the survival. In this form, the theories do seem largely overlapping. As they appear to target different levels of explanation, it can be argued that while SST and Threat simulation theory give a more detailed view on the content of dreams, PC could prove a mechanistic formalism in the form of a generative model, which could be used to answer more detailed questions. Additionally, the emotion regulation function of dreaming could be incorporated into this fold, by considering it a beneficial mechanism to aid in our social functioning. From the viewpoint of SST it would nevertheless be the overall social interaction simulation that would have been selected for, with ERT as a subspecies that is useful in maintaining our social relationships in the waking. Whether it would be so is an empirical question, not to be addressed here in further detail.

8.8 Developmental considerations of SST and a possible unifying argument

When considering social simulation as the function of dreaming in a multilevel framework a novel question arises relating to the ontogenetic level of explanation. Given that our social development goes through different phases within the lifetime of an individual, what predictions should we make for dream biases within an individual during their lifetime? Dreams have been argued to contribute to the

> "…development of psychological organization through the representational consolidation of newly emergent psychic configurations" (Fosshage, 1983, p. 658).

as well as for development and maintenance of psychological individuation, i.e., the variability between individuals (Jouvet, 1998; Siclari et al., 2020) SST has remained silent on developmental predictions, partly due to the methodological concerns on dream research in children and the resulting variability in existing data. One could make the case that a way to combine SST with the Threat simulation theory (or even PC) would be a proposition that different developmental periods or phases would be associated with differentially weighted simulation preferences, thus including both social and threat simulation. The general simulation idea—which can be restated within the exploration and exploitation terminology of reinforcement learning (see e.g., Littman, 2015)— of using existing episodic memories and abstract knowledge to construct realistic simulations of possible use for future waking life would not require any major changes. By explicating on this idea, arguably already implicit in a majority of theories, more precise hypotheses could be generated on how the developmental and environmental variables figure in dream content generation. Interestingly, this would account for a historical reversal, as children's dream research originally begun to help better understand the cognitive development of children (Piaget, 1929).

Given the individual social development would play a role in the dream contents, they should track the developmental pressure throughout the lifespan. This immediately leads to methodological problems, as we have little to no access to the dream contents of infants or small children from the time of essential social development. In fact, to begin with, there is no clear consensus at what age do dreams start. For example, based on his sleep-laboratory studies Foulkes (1982) argued dreams in earnest to begin at seven years of age, with younger children capable of only limited dream production. Dreams of children before the age seven were mainly static images that lacked representations of self, social interactions with others, and physical activity. Notably, they also included neither strangers nor frightening characters. However, using parent-collected dreams Resnick and colleagues (1994) found even four-to-five-year-old children able to give detailed continuous reports of their dreams, with active self-representations in 85% of dreams. In these reports familiar characters (71%) predominated the content. Of interest to our theoretical blueprint, the number of strangers increased as the children's' age increased from four (5%) to 8–10-year-olds (20%). Simultaneously the proportion of animals of all characters decreased from 13% (4–5-year-olds) to 3.5% (8–10-year-olds). Similarly, Van de Castle (1970) shows the percentage of reports that contain animals is over

60% for four-year-olds with a decreasing slope to slightly over 20% on 9–10-year-olds (for a visual description see Revonsuo, 2000).

The dreams of older children are limited to relatively common and realistic content (Foulkes, 1977), with family members, other familiar characters, and animals making up most the content, prioritizing play activities taking place at home and at recreational settings. However, Honig and Nealis (2012), and Woolley and Wellman (1992) have reported dreams from children as young as three using an arguably less rigorous approach. Honig and Nealis (2012) studied 3–5-year-old-children's dreams and found nearly all dreams to include other characters, approximately a third containing family members, followed by instances of strangers (10.5%), TV/movie characters (9.8%), and friends (3.4%). Using an interview paradigm Beaudet (1990, cited in Honig & Nealis, 2012) found preschool children to report other human characters in 80% of their dreams, and—in contrast to Foulkes' findings—25% to contain a monster of sorts.

Turning, then, to the other end of the individual lifespan, old age, dream contents are much less studied. Nevertheless, the sociality of dreams seems to persist (Dale et al., 2015, 2017; Lortie-Lussier et al., 2000; Waterman, 1991). In the elderly, dreams continue to simulate social interactions at the same rate as earlier, but with more positive emotions (Blick & Howe, 2010), less aggressive or friendly content and—especially in women—also less familiar characters (Dale et al., 2015; Schredl et al., 1996). However, in the longitudinal Barb Sanders dream series Domhoff (2003) found little difference in social content throughout the over 20 years of dream diary data. Overall, a theory of dreaming that would account for the changes in content via other developmental tasks would seem a viable candidate to unify various dream theories. Before arriving at such a model we should find a way to avoid some of the pitfalls in especially small children's dream report collection. Further, there is a high risk of overfitting such a complex dynamical theory via caveat explanations (i.e., reversing the explanandum–explanans relationship to account for anomalies).

8.8.1 Implications of the present thesis and future directions

These findings have strengthened the role of social phenomena as something that every proposed theory of dreaming should be able to accommodate and account for. Furthermore, it has positioned dreaming more solidly into a world simulation framework and proposed a multilevel analysis of dreams. The impact of the theory has already been evident, as it has been met with interest and even in some cases with enthusiasm in the scientific community. If, in the very least, my work has sparked interest in other researchers or provided alternative viewpoints it has served a purpose. This would be the case even if this interest were in negative form, at disproving the ideas.

Next, we should move at two fronts. First, to make clearer sense of the repertory of various existing theories, a thorough assessment should be carried out. After the conceptualization and classification of the extant dream theories has successfully been finalized, we would still be left with the question of how to place the theories in an accuracy hierarchy. In our response to Dresler's commentary on the original publication of Study I we suggested a way forward, centered around competing hypothesis formation and subsequent combination, revising and discarding of theories based on this empirical duel (Revonsuo et al., 2016b, see also Tuominen et al., in press). This would be the second task: To further develop and specify the hypotheses of SST and adjust or discard the theory accordingly to the resulting empirical findings. There are also some theoretical questions remaining. What are the specific mechanisms that select and create the social contents? Could this mechanism be best construed or modelled as a field of statistical probability distributions? What happens when this mechanism is affected by developmental or acquired brain dysfunction? If we take the adaptive function for granted, we should find that people who do not dream socially or indeed at all, should evidence some consequences in their waking lives. Therefore, we should consider populations and situations where normal social functioning is compromised or altered, such as various personality disorders, social anxiety disorder or autism, or on the other hand people suffering from a loss or gain of an attachment figure or who are otherwise in situations where the social environment is radically altered. This would also include the further examination of the *Compensation Hypothesis*, both in experimental conditions similar to our Seili experiment in Study III, but also in naturalistic settings where social seclusion is combined with an actual threat of being excluded from the existing social group such as during COVID-19, forced migration or other relocations. This would provide a proper test for the *Compensation Hypothesis* in its proposed form.

Finally, as suggested by Windt and Noreika (2011) in their presentation of the *Combination Problem*, there should be further analysis and research on the relationship between dreaming with other task-unrelated thoughts, such as mind wandering, daydreaming or prospection. A more stringent form would, however, be the formulation of computational models built on theoretical assumptions that would attempt to model the dream characteristics based on various features, such as waking events (e.g., problems to be solved, threats, social events), emotional state, cognitive state (concerns, preoccupations, wishes), or whichever feature is considered essential. This would be the opposite of a Dream Catcher test as proposed by Revonsuo (2006), as it would not attempt to predict the dream contents from neural recordings but from the waking environment and behaviour of the dreamer. A similar proposal has been stated by Schredl (2003) in his mathematical model of ICH but practically it has still proven unfeasible. Alternatively, one could train the model on all such features gathered during each day with the preceding dream report characteristics (or whole reports) and let it extract features through a convolutional neural net, and assess how these predictions would fare against the actual characteristics of the dream report. In the case of the latter, the model would use the new data as additional information on which to ever increase the model fit. If the predictions would not prove accurate we could consider the relationship between waking and dreaming to be either overstated or more complex than currently proposed.

What, then, should we conclude from the thoroughly social aspect of our other major state of consciousness? My tentative hypothesis for the future goes beyond the social aspects of dreaming and proposes sociality as constitutive of consciousness in general. There is ample evidence that our basic cognition is always already primed for social content. This is evident from, for example, such phenomena as pareidolia, the tendency to interpret inanimate patterns as social—for example seeing the face on the moon, Jesus in toast or a primitive smiley face in an electric socket (Katao & Mugitani, 2015; Liu et al., 2014; Palmer & Clifford, 2020). Similarly, we inhabit what Daniel Dennett (1989) has termed the intentional stance, and interpret behaviour to be intentional, and go as far as anthropomorphise non-human animals and machines to have similar intentional states. Following such reasoning, it can be argued that this *a priori* social priming bears such strength that when consciousness is left unbound, not anchored to the "ground truth" of sensory perception, it infuses our reality with social contents. This, however, does not remove the possible functionality argument of dreaming, quite the opposite. We can still stand behind our argument that dream social simulation carries an evolutionary function, however, what this would allow is to move the explanatory variable further beyond. It would be our consciousness in general that is attuned to sociality for evolutionary concerns, and this is most evident in cases of task-unrelated thought, such as dreaming, mind wandering, prospection or daydreaming where the senses do not limit such content. It should be noted that similar tendency for other proposed dream content, threatening situations, do not seem to be found as often in mind wandering, prospection or daydreaming as social contents[48] albeit this area remains little studied (however, see Bulley et al., 2017; Suddendorff, 2006; Taylor & Schneider). It thus seems sociality could be more essential for task-unrelated thought in general than threatening content. This does not exclude the possibility that threats are especially simulated in dreams as a specific function.

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[48] Social threats (negative stereotyping) seem to invoke mind wandering, however, and lead to worse task performance (Jordano & Touron, 2017; Mrazek et al., 2011). The contents of this mind wandering was not assessed. (For opposite results, see Brown & Harkins, 2016)

8.8.2 Brief note on COVID-19 and dream research

Coinciding with the preparation of this thesis, in 2019 a coronavirus epidemic began in Wuhan, China, and by early 2020 it had reached pandemic proportions. This unprecedented catastrophe has brought in its wake a cascade of consequences that could arguably help us uncover some of the questions about the relationship between dream contents and waking events and environments (Tuominen et al., in press). Here, I will limit my consideration to the aspects relevant for SST and its future study. The pandemic is separated into two aspects: the impact of the virus and its health outcomes, and the impact of the mitigation efforts. While the former aspect may be of more interest for testing hypotheses of the Threat simulation theory, CCH or ERT, it is the latter that has been the source of the major upheaval in our everyday lives. In order to attempt to mitigate and slow down the spread of the virus, governments have imposed various measures, such stay-at-home orders, school closures, mask mandates and social distancing recommendations.

While the amount of data on individual and governmental responses to the pandemic across the globe is unique (see e.g., Hale et al., 2020; Lieberoth et al., 2021; Yamada et al., 2020) these are often cross-sectional in nature and only rarely contain questions about dreams. To peer into the longitudinal change in dream contents a fortnight-long dream and mind wandering report collection was carried out in Finland, the United Kingdom and Australia by the researchers from the University of Turku, Cambridge University, Queens University of London, and Monash University, respectively. For SST such datasets are valuable, as they allow us to measure the impact of, for example, perceived stress, social isolation, or changes in behaviour (i.e., physical distancing) and outlook (i.e., masks) on the social contents of dreams. For instance, on the effects of social isolation the findings from Study III on the impact of social seclusion become useful, as they serve as a contrasting measure where the social isolation was carried out without a real risk of losing one's in-group. During the pandemic this is a realistic threat, and thus could either help combine or separate SST from the Threat simulation theory, and will illuminate the scope and predictive power of these theories.

8.9 Conclusion

In this thesis I presented the SST, a theory to account for a plausible social function for dreaming. Empirical research carried out to test the underlying hypotheses derived from this theory have supported the *Sociality Bias* of dreams as predisposed toward social content and seem to carry out a bond strengthening function, albeit in a more complicated fashion than the *Strengthening Hypothesis* was originally proposed. Preliminary support was also gained for the *Practise and Preparation Hypothesis*, but more specific tests on individual variation in social skills, their development, and dream content remain to be tested. However, the *Compensation Hypothesis* did not gain support, and dream sociality was found to remain relatively stable regardless of the actual number of waking social interactions. Taken together, SST forms a cohesive account for dreaming, and its strengths are in, first, having a rigorous theoretical background that covers not only dreams but our conscious experience in general, and, second, covering a large amount of current research findings on dream report contents. With this thesis I hope to have positioned dreaming more strongly into the centre of a multidisciplinary scientific investigation. SST provides a useful theoretical viewpoint, a *tool* we can work with, as it creates novel hypotheses and attempts to moor dream research into a more rigorous research program. When this tool no longer is useful (or, alternatively, when its accuracy has been repeatedly verified) we hopefully have moved toward a more elegant unified theory of dreaming. This in turn can help illuminate the questions regarding consciousness in general, whether bound by sensory input or unbound and internally self-organizing.

Abbreviations

AASM	American Academy of Sleep Medicine
AIM	Activation-input-modulation model
BMI	Body mass index
BST	Beddit Sleep Tracker
CCH	Cognitive Continuity Hypothesis
CH	Continuity hypothesis
CI	Confidence interval
DC	Dream Catcher test
DMN	Default mode network
DSM-IV	Diagnostic and Statistical Manual for Mental Disorders 4th edition
DQN	Deep Q Network
EEA	Environment of evolutionary adaptedness
EEG	Electroencephalography
EMG	Electromyography
EOG	Electro-oculography
ERT	Emotion Regulation Theory
ESM	Experience sampling method
FEP	Free energy principle
fMRI	Functional magnetic resonance imaging
fMRI-EEG	Functional magnetic resonance imaging – electroencephalography
fNIRS	Functional near-infrared spectroscopy
FPN	Frontoparietal network
GLMM	Generalized linear mixed model
HVdC	Hall and Van de Castle content analysis method
ICH	Incorporation Continuity Hypothesis
II	Imagined Interaction theory
LMM	Linear mixed model
N1	Non-rapid eye movement sleep stage 1
N2	Non-rapid eye movement sleep stage 2
N3	Non-rapid eye movement sleep stage 3
NEXTUP	Network exploration to understand possibilities

NREM	Non-rapid eye movement sleep
NTB	Need to Belong questionnaire
OR	Odds Ratio
PC	Predictive Coding
PET	Positron emission tomography
PHQ-9	Patient Health Questionnaire
PGO	Ponto-Geniculo-Occipital waves
PSG	Polysomnogram
REM	Rapid eye movement sleep
REML	Rapid eye movement sleep latency
RFQ	Reflective functioning questionnaire
SCS	Social Content Scale
SE	Sleep Efficiency
SOL	Sleep onset latency
SST	Social Simulation Theory
SWS	Slow wave sleep
tACS	Transcranial alternating current stimulation
tDCS	Transcranial direct current stimulation
TMS	Transcranial magnetic stimulation
ToM	Theory of Mind
WASO	Wake after sleep onset

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TURUN
YLIOPISTO
UNIVERSITY
OF TURKU

Painosalama, Turku, Finland 2022

ISBN 978-951-29-8802-0 (PRINT)
ISBN 978-951-29-8803-7 (PDF)
ISSN 0082-6987 (Print)
ISSN 2343-3191 (Online)