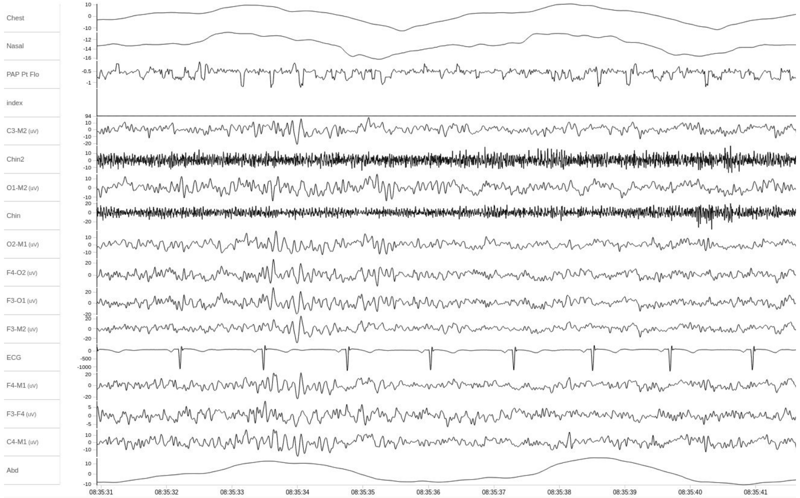
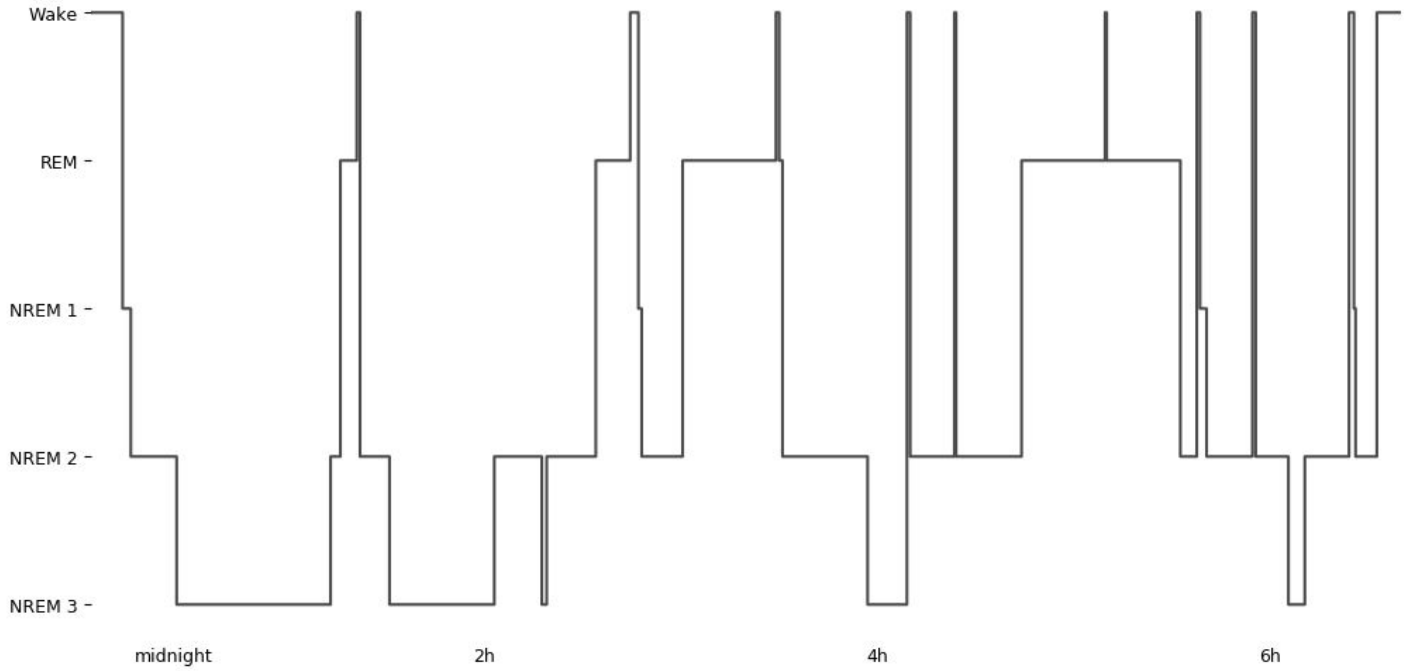
Prediction of brain Deep Sleep Slow Wave Activity

Valentin Thorey / Head of algorithms, machine learning / Dreem Paris

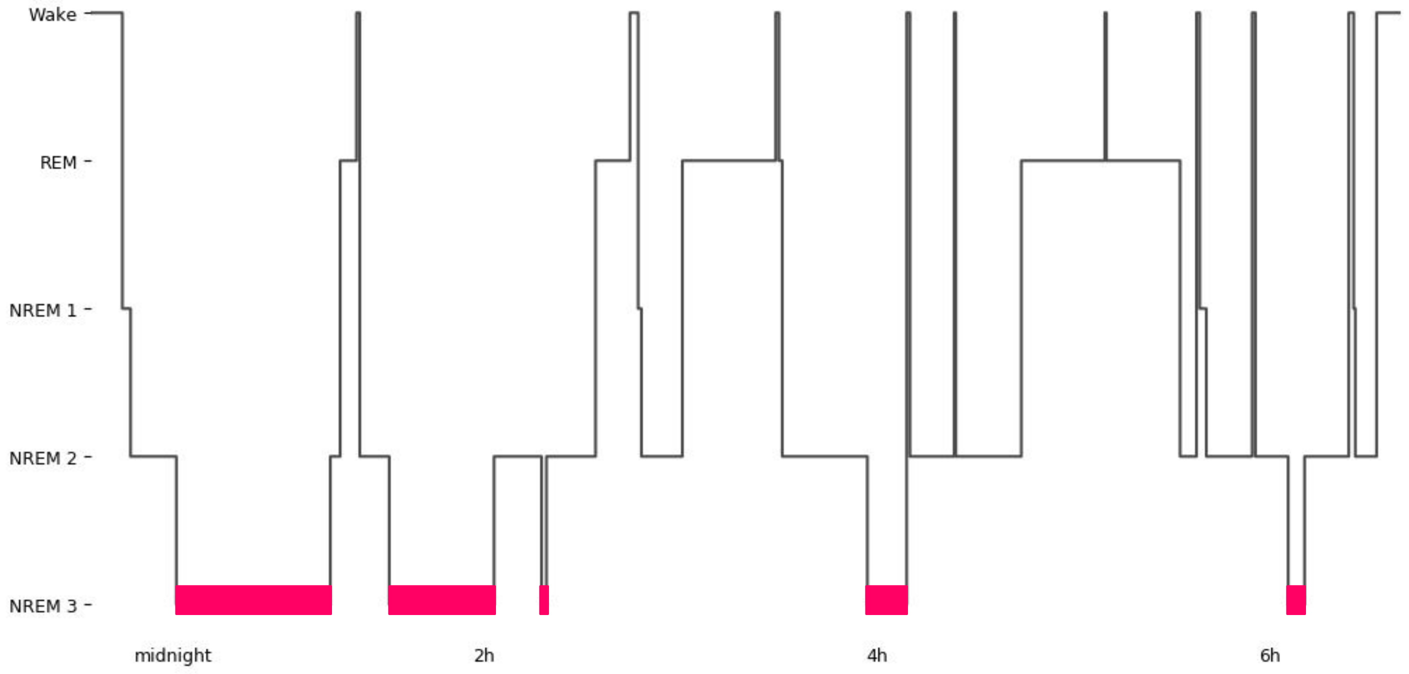


Polysomnography



Hypnogram

dreem



Deep Sleep

Slow Wave activity

dreem

Brain Energy Restoration

Learning, Memory consolidation

Hormone Releasing

Role of Deep Sleep

Aging

Stress

Neurodegenerative diseases

Deep Sleep can be degraded

frontiers in Human Neuroscience

ORIGINAL RESEARCH
published: 08 March 2018
doi: 10.3389/fnhum.2018.00088

Performance

frontiers in SYSTEMS NEUROSCIENCE

Enhancement of sleep slo
and practical consequenc

Michele Bellesi[1], Brady A. Riedner[1], Gary N. G

[1] Department of Psychiatry, University of Wisconsin-Madison, Madiso
[2] Clinical Sites Research Program, Philips Group Innovation, Briarcliff,

Edited by:
Jason Robert Gerstner, Washington State University, USA
Reviewed by:
Robert Stickgold, Beth Israel Deaconess Medical Center/Harvard Medical School, USA
Lyle J. Graham, Centre National de la Recherche Scientifique, France
*Correspondence:
Giulio Tononi, Department of Psychiatry, University of Wisconsin-Madison, 6001 Research Park Blvd Madison, WI 53719, USA
e-mail: gtononi@wisc.edu

Even modest sleep invariably associated occurrence of local to cognitive and me sleep in memory co Thus, the implemen arousals or lightenin review the evidence transcranial direct-cu these methods are chronic long-term ex enhance slow waves (KC), a peripheral ev acoustic stimulation likely through the ac system. In addition, well as exact timing discuss automated a parameters in a clo avoid undesirable ar the generation of sl acoustic stimulation enhancement.

Keywords: EEG, acoustic stimulation, arousal systems, closed-loop, N

Sleep is thought to be a universal phenomenon. Despite representing a behavioral state of almost total disconnection from the environment and, therefore, being inherently dangerous, sleep has been identified in every species carefully studied so far (Tobler, 2005; Cirelli and Tononi, 2008; Tononi and Cirelli, 2012). It is unknown when and why sleep emerged in evolu-

local regulation of sleep (and Tobler, 2008; Hanlon Hung et al., 2013).
It has been proposed "synaptic homeostasis", wh plasticity of the brain (To

J. Sleep Res. (2012) Regular Resear

Induction of slow oscillations by rhythmic acoustic stin

HONG-VIET V. NGO[1,2], JENS C. CLAUSSEN[1], JAN BORN[3,4] AND MATTHIAS MÖLLE[3,4]

[1]Institute for Neuro- and Bioinformatics, University of Lübeck, Germany, [2]Graduate School for Computing in Medicine an University of Lübeck, Germany, and Behavioral Neurobiology, Ur

Keywords
auditory, entrainment, stimulatio oscillations

Correspondence
Matthias Mölle, Department of Neuroendocrinology, University Ratzeburger, Allee 160, Hs. 50, Germany.
Tel.: +49 451 500 3643;
fax: +49 451 500 3640;
e-mail: moelle@kfg.uni-luebeck.

Accepted in revised form 24 Jun received 6 March 2012

DOI: 10.1111/j.1365-2869.2012.

INTRODUCTION

Sleep slow oscillations (SOs sleep (SWS) as they are (amplitude >75 µV) recorde (EEG). They emerge from neuronal networks undergoin of membrane depolarizatio

Letter | Published: 05 November 2006

Boosting slow oscillatic potentiates memory

Lisa Marshall, Halla Helgadóttir, Matthias Mölle & J

Nature 444, 610–613 (30 November 2006) | Downloa

Abstract

There is compelling evidence that slee consolidation of new memories[1]. This to slow (<1 Hz) potential oscillations, the prefrontal neocortex and characte oscillations in brain potentials are co epiphenomena that reflect synchroniz networks, which links the membrane neurons in time[5]. Whether brain poter equivalent have any physiological mea easily be investigated by inducing the fields of interest[6,7,8]. Here we show th potential fields by transcranial applic Hz) during early nocturnal non-rapid- period of emerging slow wave sleep, enhances the retention of hippocampus-dependent declarative memories in healthy humans. The slowly oscillating potential stimulation induced an immediate increase in slow wave sleep, endogenous cortical slow oscillations and slow spindle activity in the frontal cortex. Brain stimulation with oscillations

Please cite this article in press as: Ngo et al., Auditory Closed-Loop Stimulation of the Sleep Slow Oscillation Enhances Memory, Neuron (2013), http://dx.doi.org/10.1016/j.neuron.2013.03.006

Neuron
Article

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Auditory Closed-Loop Stimulation of the Sleep Slow Oscillation Enhances Memory

Hong-Viet V. Ngo,[1,2,3] Thomas Martinetz,[2] Jan Born,[1,4,*] and Matthias Mölle[1,4]
[1]Institute of Medical Psychology and Behavioral Neurobiology, and Center for Integrative Neuroscience, University of Tübingen, 72076 Tübingen, Germany
[2]Institute for Neuro- and Bioinformatics
[3]Graduate School for Computing in Medicine and Life Sciences
[4]Department of Neuroendocrinology
University of Lübeck, 23538 Lübeck, Germany
*Correspondence: jan.born@uni-tuebingen.de
http://dx.doi.org/10.1016/j.neuron.2013.03.006

SUMMARY

Brain rhythms regulate information processing in different states to enable learning and memory formation. The <1 Hz sleep slow oscillation hallmarks slow-wave sleep and is critical to memory consolidation. Here we show in sleeping humans that auditory stimulation in phase with the ongoing rhythmic occurrence of slow oscillation up states profoundly enhances the slow oscillation rhythm, phase-coupled spindle activity, and, consequently, the consolidation of declarative memory. Stimulation out of phase with the ongoing slow oscillation rhythm remained ineffective. Closed-loop in-phase stimulation provides a straight-forward tool to enhance sleep rhythms and their functional efficacy.

INTRODUCTION

Brain activity oscillates at different frequencies, reflecting synchronized activity that organizes information processing and communication in neuronal cortical networks in a state-dependent manner (Buzsáki and Draguhn, 2004; Varela et al., 2001). The <1 Hz slow oscillation (SO) represents the most distinct of these oscillations that hallmark the electroencephalogram (EEG) during slow-wave sleep (SWS) (Steriade, 2006; Timofeev, 2011). The SO is generated in cortical and thalamic networks and reflects global synchronous neural activity alternating between up states of membrane depolarization and increased excitability and down states of hyperpolarization and widespread neuronal quiescence, which spreads across the neocortex, also capturing subcortical structures like the hippocampus (Isomura et al., 2006; Massimini et al., 2004). Importantly, the SO critically contributes to information processing during sleep: apart from an involvement in synaptic downscaling and homeostasis (Tononi and Cirelli, 2006), SOs play a causal role for the consolidation of memory (Chauvette et al., 2012; Diekelmann and Born, 2010; Marshall et al., 2006). For this consolidating function, the

The obvious functional importance has stimulated attempts to induce synchronized cortical SO activity through external stimulation, mainly by rhythmic electrical, transmagnetic, and auditory stimulation in humans and rats (Marshall et al., 2006; Massimini et al., 2007; Tononi et al., 2010; Vyazovskiy et al., 2009). Importantly, such studies imposed rhythms on the brain disregarding the phase of ongoing endogenous oscillating activity, which might explain the overall limited functional enhancement in memory retention accompanying SO stimulation. Here, we utilized the ongoing oscillatory EEG activity to apply, in a closed-loop feedback system, auditory stimulation in synchrony with the brain's own rhythm, thereby enhancing and extending trains of SOs during sleep.

RESULTS

Auditory In-Phase Stimulation Induces SO Activity and Enhances Memory Consolidation

Subjects (n = 11) were tested on two experimental nights, balanced in order. In the Stimulation condition, upon online detection of an SO negative half-wave peak during nonrapid eye movement (non-REM) sleep, two auditory stimuli (50 ms, pink noise) were delivered such that they concurred in time with the predicted up phases of the detected and the succeeding SOs (Figure 1A). The stimulation started with onset of consolidated non-REM sleep and was discontinued after 210 min. During the Sham condition, stimulation time points were marked but no stimulation was applied. The detection routine was resumed 2.5 s after presentation of the second auditory stimulus.

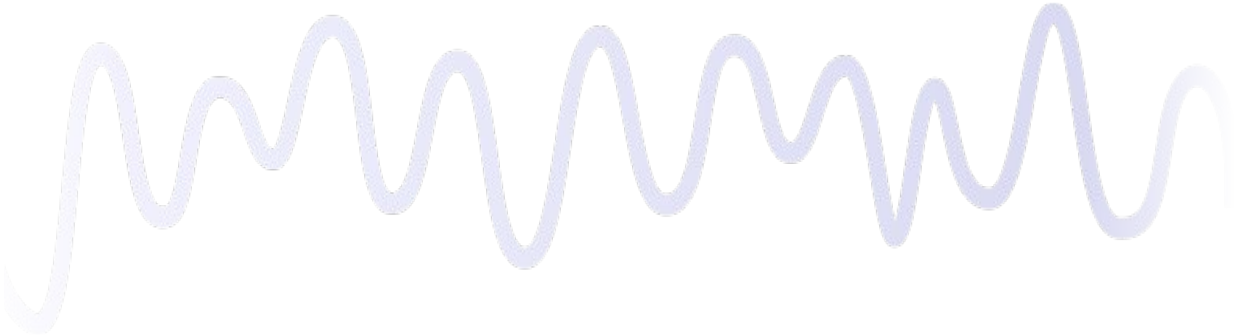
Averaging the EEG time locked to the first auditory stimulus revealed a clear increase in slow oscillatory activity, in comparison with the Sham condition (Figure 1B). Whereas in the Sham condition an individual SO cycle occurred, the two auditory stimuli in phase with the predicted SO up states formed a sequence of three succeeding SO cycles (in the following referred to as an "SO train"). This suggests a resonating response of the network induced by the in-phase stimulation. The decrease in SO amplitude across these trains might reflect that the second auditory stimulus did not always hit the optimal SO up state phase (due

Deep Sleep Enhancement

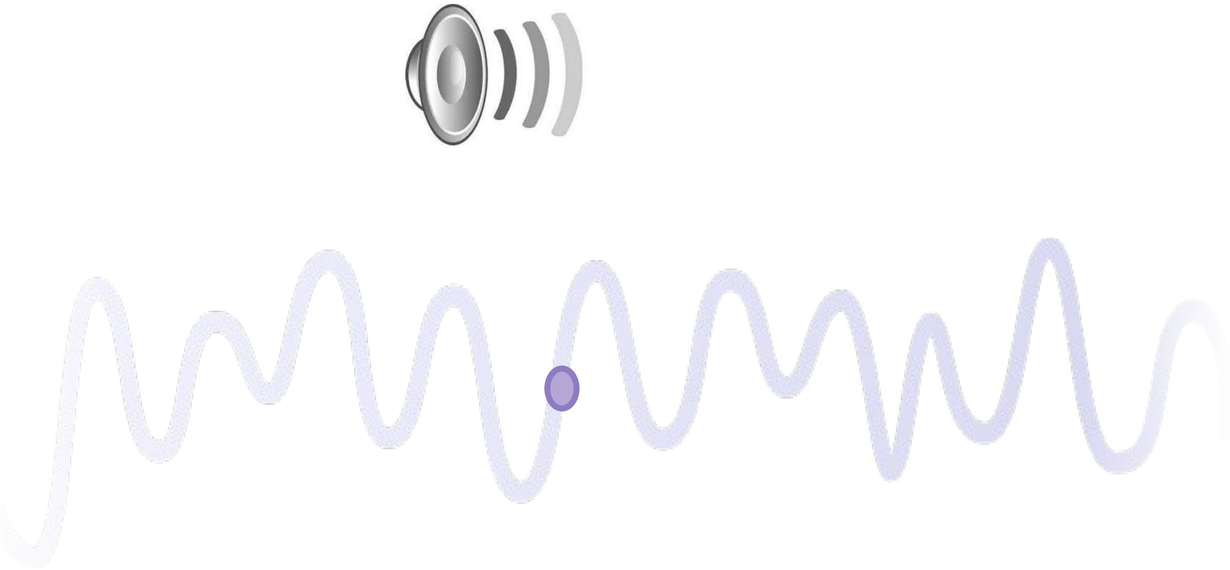
dreem

~ 1Hz

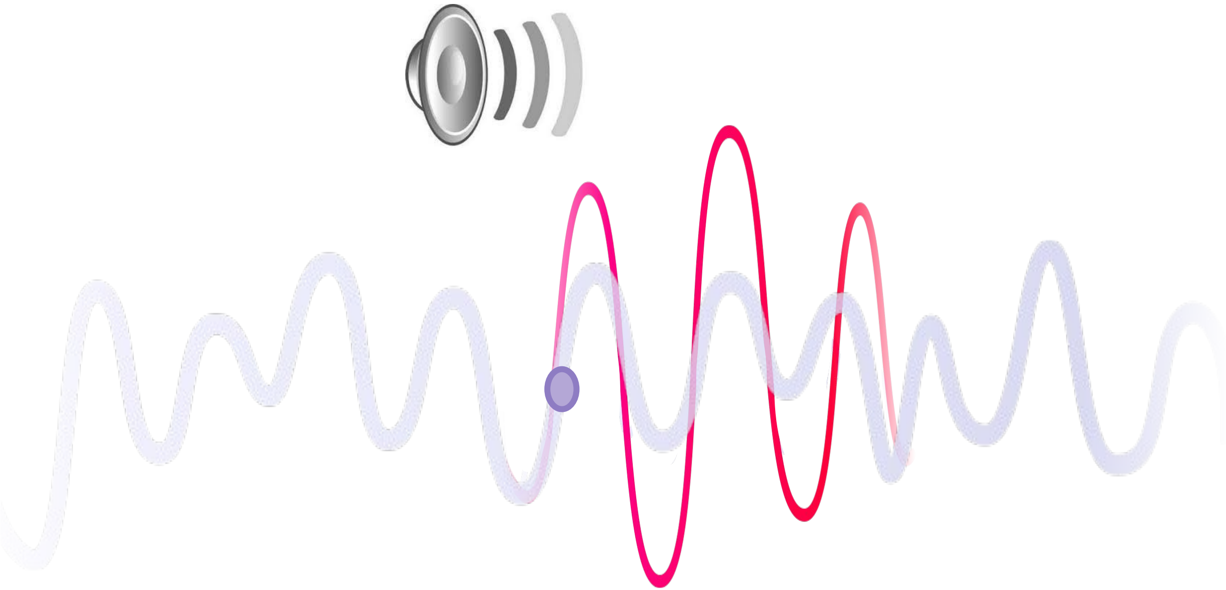
Slow Wave activity



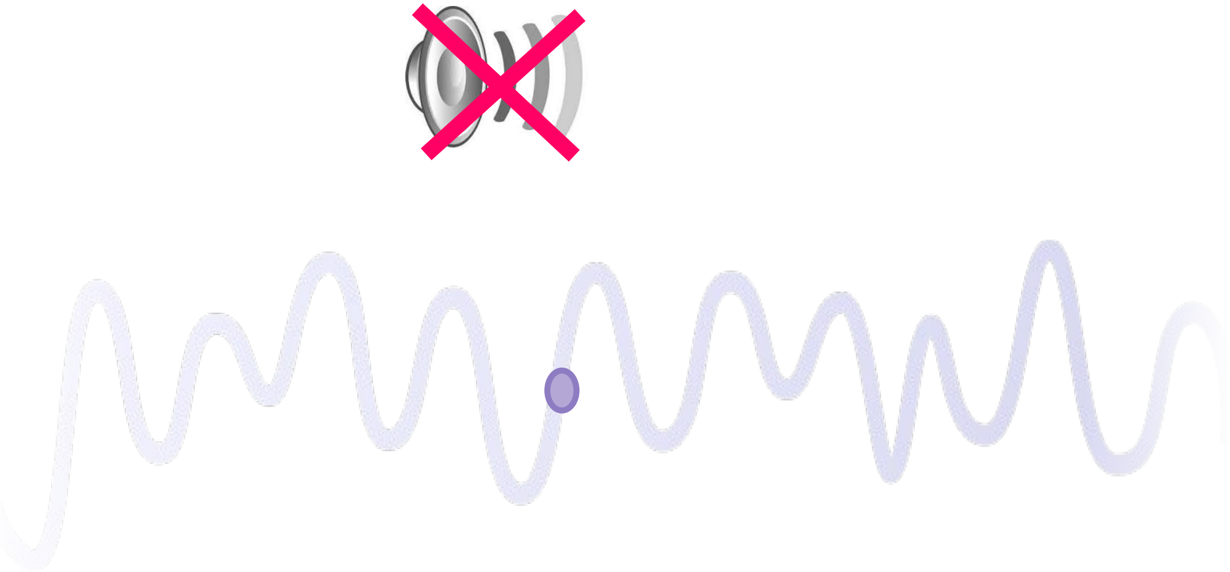
Deep Sleep Stimulation



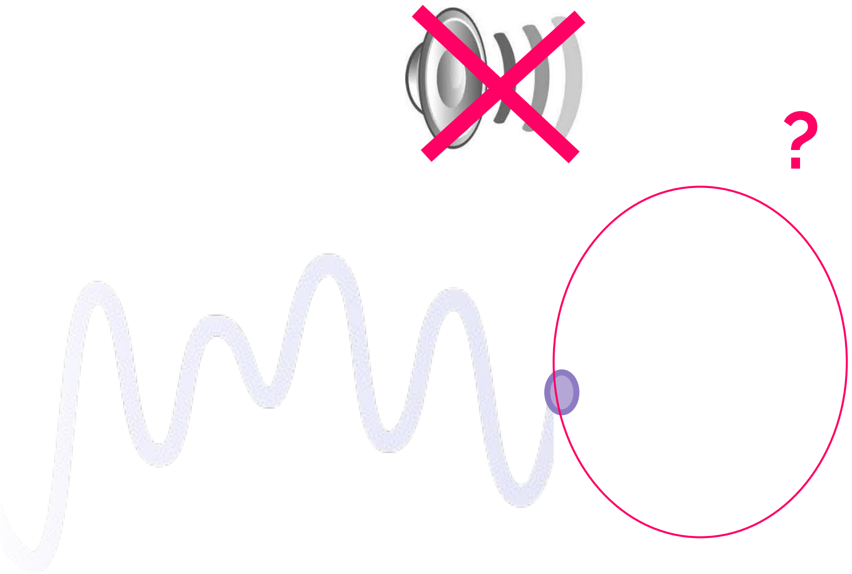
Deep Sleep Stimulation



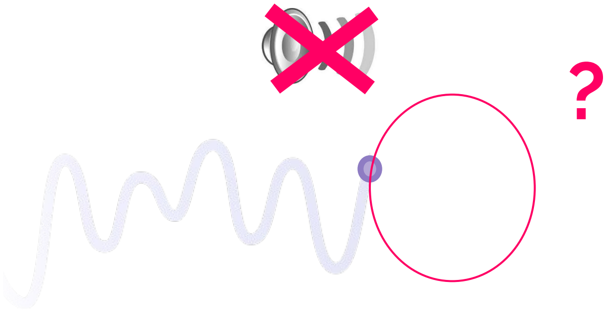
Deep Sleep Stimulation



Sham Condition



Is there a Slow Oscillation just after?



0. No slow oscillation

1. Slow Oscillation of low amplitude

2. Slow Oscillation of high amplitude

3 classes

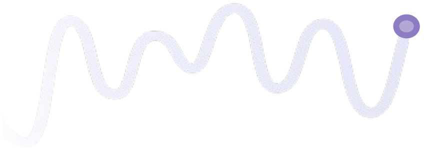
x_i

y_i

Metadata: 10 features

0. Number of previous slow oscillations
1. Mean amplitude of previous slow oscillations
2. Mean duration of previous slow oscillations
3. Amplitude of the current slow oscillation
4. Duration of the current slow oscillation
5. Current Sleep stage
6. Time elapsed since the person fell asleep
7. Time spent in deep sleep so far
8. Time spent in light sleep so far
9. Time spent in rem sleep so far
10. Time spent in wake sleep so far

EEG for 10 seconds at 125 Hz: 1250 features



Integer: 0, 1 or 2

In the following second:

0: no slow oscillation

1: low amplitude slow oscillation

2: high amplitude slow oscillation

Dataset

500 000 Anonymized samples from 9610 recordings and 1699 users

- train: 261 634 samples (850 users)
- test: 238 366 samples (879 users)

Dreem Data

Accuracy = ratio of correct predictions

Risk

Random Forest on basic features
Accuracy = 0.505

Benchmark

dreem