

Sleep Enhancement by Sound Stimulation

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ABSTRACT

Recently research groups have reported that the depth and/or duration of Slow Wave Sleep (SWS) can be increased and memory consolidation can be improved by playing short sounds with approximately 1-2 second intervals during or prior to SWS. These studies have used sounds with neutral or negative valence: sinusoidal 1-kHz tones or short pink noise bursts.

We have confirmed memory improvement with own experiments using short pink noise bursts. Since music therapy research shows beneficial effects of pleasant, natural sounds and music, the sounds in the experiments may have been suboptimal, and we are currently extending these finding using optimized sound stimulus. In this work in progress experiment setup is described.

1. INTRODUCTION

There is some recent evidence that short sounds played during the deep sleep can enhance the power in the delta rhythm band of the electroencephalogram (EEG) [1], [2], [3], [4], [5]. Importantly, research seems to suggest that the stronger delta rhythm observed in the EEG during the stimulation with sound resulted in similar beneficial effects on memory and cognition that are observed with naturally occurring strong delta activity during sleep [3], i.e., the rhythmically presented sounds increased the memory recall. Better and deeper sleep in general is associated with cognitive and emotional benefits.

When a sound starts and reaches the outer, middle, and finally the inner ear, a series of neural events takes place. The information about the sound, its features and properties, is transferred to the different nuclei of the auditory system, giving rise to well-determined synchronous activity of the neurons in each nucleus. The characteristics of the neural activity in the nuclei depend on the sound parameters, especially the rise time, attack properties, amplitude, and the frequency content of the sound. Specifically, sounds with fast rise times and large amplitudes evoke the strongest and most synchronous neural activity. In order for a sound to evoke such clear brain activity at the thalamic and cortical level, it must be loud enough, the rise time must be fast enough (faster than at least 50 ms, preferably on the order of 5-10 ms), the sound should be preceded by a silence or a relatively quiet period of at least 200 ms, and the sound itself should contain a large selection of audible frequencies.

The neural activity evoked by sounds is not restricted to the auditory system, but has further-reaching impacts. Several areas of the brain receive input on sound-

related events. For example, studies in brain responses to music have shown that large brain areas are activated by listening to music, including the areas in the somatosensory and motor systems, cerebellum, and large areas of the frontal cortex.

During sleep, the processing of sounds in the brain differs greatly from that occurring during awake state. Several of the typical cortical event-related potentials (ERPs) are missing or appear with a slow latency and smaller or larger amplitude compared to awake state.

Sounds presented during sleep may disturb sleep and may have detrimental effects of memory consolidation during sleep. Sleeping in noisy surroundings may result in poor quality sleep and in the morning, the individual may feel less refreshed by the sleep than after sleeping in quiet conditions. There are, however, examples of positive effects of sound in the situation of falling asleep. In music therapy, for example, soft music may be used to help the patients fall asleep. Masking music or white noise is also sometimes used to help the patients fall asleep when sleeping in noisy conditions with disturbing noise like conversation. In order for the falling asleep to occur optimally and the patients to stay asleep despite the sounds, however, the sounds must be of low amplitude and subjectively very pleasant.

In our previous listening test [6], we compared the pleasantness of 10 short instrumental sounds with fast rise times. These sounds belonged to four instrument families: Western orchestral percussions, african percussions (kalimba), marimbas, and vibraphones. Those tests, performed in day-light in office surroundings, identified 3 most pleasant instrument sounds. These sounds were studied in a setup mimicking sleeping situations [7] and are used in this study. We are also comparing physiological sleep structure and memory consolidation results of these optimized sounds to previously results of pink noise bursts.

2. METHODS

2.1. Laboratory

Three identical sleep room setups were used in the Sleep Laboratory of Finnish Institute of Occupational Health, Helsinki, Finland. Recordings were performed in sound isolated and temperature controlled sleep rooms.

2.2. Hardware

Hardware included eight channel wireless 500 Hz DC coupled EEG recorder Enobio and first generation Microsoft

Surface Pro tablet. Battery capacity of Enobio devices (Firmware version 1.2) was sufficient (12-14 hours) for sleep recordings. For overnight recordings Surface tablets running Windows 8 were disconnected from WLAN networks. USB cables were used to extend Bluetooth receivers (DeLOCK Micro Bluetooth 2.1) from control room to individual sleep rooms. Setup can be easily applied to home use without wires between computer and subject.

2.3. Auditory stimuli

There were four different auditory stimuli in this experiment: pink noise bursts [2], [3], kalimba, marimba and vibraphone [6], [7].

Auditory stimuli were played using USB soundcard (Nuforce Icon uDAC2) through Genelec 2029A (Iisalmi, Finland) speakers. Sampling frequency was 44100 Hz and 16 bits resolution was used. Mono speaker was placed 125 cm over the head of sleeping subjects. Sound stimulus was delivered 600 ms after detected DOWN state during deep sleep. Sound level was individually adjusted for a maximum of 15 dB HL. Sound level was automatically adjusted by automatic algorithm [8]. Audio card headphone output was used to synchronize clocks in this wireless setup in the beginning and in the end of each recording.

2.4. Physiological recordings

Recorded polysomnography channels are E1, E2, Fpz, Fz, Oz, M1, M2, and EMG as recommended by American Association for Sleep Medicine (AASM) [9]. Common mode sense (CMS) reference electrode was placed at Cz and driven right leg (DRL) at CPz. As device was originally intended for daytime EEG recordings, custom holder was developed to enable placing it over sternum. This positions enabled also the use of built-in 3D accelerometer as positional sensor.

From EEG visual sleep stage scoring [9] is done.

2.5. Memory and subjective measurement

Overnight memory consolidation is measured by word-pairs [3]. Learning of 120 word-pairs is done 21:00 followed by immediate recall and delayed recall at 07:00. Different lists are used in every day. Sleepiness, and mood is measured by visual scales.

3. EXPERIMENT

Our aim is to measure 20-30 subjects between 18-65 year with normal sleep pattern and normal hearing. Subjects are measured from every night from Monday to Friday. In current study four conditions are randomized: 1) no sound as baseline 2) pink noise for 8 hours to replicate previous work 3) pink noise for first 4 hours to minimize possible late night arousal effects 4) subject's selected sound for 8 hours to assess whether the pleasantness of the sound has an effect. Sound is synchronized to EEG delta waves and volume controlled by automatic sleep depth analysis. Subject selected sound was one of three options [7] selected most pleasant by subject in Monday evening.

4. STATUS

On a date of submission seventeen subjects have undergone four measurement nights. Difference between memory consolidation between morning recall and immediate recall is used as main outcome as in earlier study [3]. From EEG sleep stages are visually scored. Also sound triggered evoked potentials, slow oscillations are calculated and compared between nights. It is postulated that user selected sounds would provide EEG synchronization and memory improvement similarly to previously used pink noise bursts but without previously observed arousals.

5. ACKNOWLEDGMENT

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