Auditory evoked potentials in lucid dreams: A dissertation summary

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Summary. Are lucidly dreaming subjects able to discriminate between two different auditory stimuli using an oddball paradigm? How does the evoked potential (P300) in the EEG during this task look during lucidity, as compared to wakefulness and to non-lucid REM sleep? These are the central questions in Dr. Johannes Oliver Strelen's dissertation, which is summarized in English language in this article. Six experienced lucid dreamers underwent polysomnographic recordings in the sleep laboratory for a total of 21 nights. Their task was to move their eyes from left to right, whenever they heard the target stimulus of an oddball paradigm, which was presented throughout the whole night. Three of the six subjects experienced a verified lucid dream and conducted the given task within it. The performance (correct responses) in the oddball task during lucid dreaming was worse than during wakefulness, but significantly better than what could be explained by chance. Thus, Strelen showed,that it is possible to react to simple auditory stimuli with a pre-defined eye movement, while dreaming lucidly, without waking up in between. Moreover, for two of his subjects, Strelen analyzed the auditory evoked potential (P300) of the EEG signal during the oddball paradigm. In one case, he found a clear, in the other case a unclear P300 peak. The morphology of the P300 EEG pattern for the correctly answered target stimuli during lucid dreaming was similar to the P300 EEG pattern during wakefulness, suggesting that information processing during lucid dreams is closer to wakefulness than to non-lucid REM sleep.

Keywords: Lucid dreaming, auditory evoked potentials, P300, dissertation summary

1. Introduction

This review summarizes the most important results from the dissertation of Dr. Johannes Oliver Strelen, which was handed in at the Johannes Gutenberg University, Mainz, Germany, in 2006 under the title "Akustisch evozierte Potenziale bei luziden Träumen - eine Untersuchung über diskriminierendes Wahrnehmen und selektives Beantworten von Tönen in REM-Schlaf" (Auditory evoked potentials in lucid dreams – an investigation of discriminative perception and selective answering of tones during REM sleep). The goal of this review is to make the study's main findings available to the scientific community by translating them into English, as they might be of great interest to other lucid dream researchers, and possibly to researchers from other fields, as well.

2. Summary of Strelen's dissertation

2.1. Motivation of the study and study goals

Even though evoked potentials can deliver information about the consciousness state, they have not yet been used for lucidly dreaming subjects – other than, for example, for the sleep stage N1, for which it was demonstrated that they describe the subjective and objective state of consciousness better than the spontaneous EEG (Campbell and Colrain, 2002).

Investigating evoked potentials during lucid dreams could thus lead to new insights about the phenomenon of lucid dreams. Besides this, Strelen sees it as an exciting challenge to let experienced lucid dreamers conduct the paradox task of reacting to waking world stimuli during sleep with eye signals.

Thus, the aim of Strelen's study was to present auditory stimuli using an oddball paradigm during lucid dreams and to analyze both the performance of the subjects during the oddball task, as well as the evoked potentials in the EEG signal.

2.2. Methods

2.2.1 *Participants*

Six healthy volunteers (three male, three female, aged 21-50) were recorded at the Stanford Psychophysiology Laboratory in the year 2001. The subjects were experienced lucid dreamers (based on self-assessment), and underwent polysomnographic recordings for 6, 7, 5, 1, 1, and 1 nights. No adaptation night was recorded. The subjects went to bed at their preferred time and slept ad libitum. Written informed consent was obtained for the study.

2.2.2 *Materials*

Stimuli were presented using in-ear speakers in the left ear throughout the whole night at 30 dB above the individual perceptional threshold. The stimuli consisted of 70 ms long sine wave tones in random order at either 1000 Hz (80% probability, non-target stimuli) or 2000 Hz (20 % probability, target stimuli), according to the oddball paradigm.

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Table 1. Definitions

Definitions
- lucid dream: a dream in which the dreamer knows that he or she is dreaming
- evoked potential: event-related brain activity pattern following a (e. g. auditory) stimulus, measured using EEG
- oddball paradigm: a series of stimuli of two types, one with high probability (non-target items) and one with low probability (target items)
- P300: evoked potential measured around 300 ms after stimulus onset, which is thought to reflect processes involved in stimulus evaluation, e. g. in an oddball paradigm (Sutton et al., 1965)

The single stimuli were each followed by 2.0 ± 0.1 seconds of silence.

A Neuroscan SynAmps system was used for recording physiological (EOG, EMG, ECG) and EEG data (28 channels, using the 10-20 system). Impedances were kept below 5 kOhm. The data were sampled at 1000 Hz. Baseline correction was applied to the EEG data, as well as filtering (0.3 – 30 Hz) and artifact rejection.

2.2.3 The task of the subjects

The task, which the subjects were supposed to conduct in case they experienced a lucid dream during the nights in the sleep laboratory consisted of:

- moving the eyes left-right-left-right (LRLR) when reaching lucidity,
- listening to the auditory stimuli and moving the eyes another time LRLR when incorporating them into the lucid dream,
- moving the eyes LR immediately after each of the target (higher pitched) auditory stimuli, but not after the non-target (lower pitched) stimuli,
- moving the eyes LRLRLRLR directly after waking up,
- writing down a dream report after each waking up from a lucid dream, as well as filling out a questionnaire about the tones.

The subjects were asked to practice their task for at least 10 minutes a day during wakefulness during the days before the sleep laboratory nights. The task was also conducted at the sleep laboratory during wakefulness for 10 minutes (wakefulness condition).

2.2.4 Data analyses

Sleep stages were scored according to the criteria of Rechtschaffen and Kales (1968).

Only those lucid dreams were used for further analysis, which took place during REM sleep, were marked clearly by a LRLR eye signal in the beginning of the lucid dream, and had a written dream report indicating subjective lucidity.

For the evaluation of the oddball task, the LR eye movements were identified without knowing the timing or the category of the tones. For each LR eye movement, the tone was assigned, which was played during the 2000 ms before the eye movement. The oddball task was counted, if the subject tried to conduct the task (even if he or she did not succeed in hearing the tones), and if there was at least one target tone during the try.

The auditory evoked potentials were calculated for four conditions: wakefulness (based on the training periods before going to sleep and after waking up in the morning), non-lucid REM sleep, lucid REM sleep with signals to the oddball tones, and lucid REM sleep without signals to the oddball tones (if the task was not conducted during lucidity). If sufficient data was available, the EEG data was averaged for each condition, both for the target and the non-target tones, and the P300 EEG pattern was identified. Furthermore, the latency and amplitude were determined.

2.3. Results

2.3.1 General lucid dreaming results

Five of the six subjects subjectively experienced a lucid dream. In total, there were 23 subjective lucid dreams. Eighteen of these lucid dreams could be verified in four subjects, i.e. they took place during REM sleep and were clearly marked with a LRLR eye signal.

2.3.2 Oddball task

The oddball task was correctly conducted in 10 of the 18 verified lucid dreams, by three subjects. Reasons for not correctly conducting the task were lack of time (too short lucidity phase), forgetting the task or remembering it in a false way, giving unclear eye signals, or being distracted by the dream content (e. g. distractions by other dream characters, or the dream was too loud, i. e. louder than the stimuli).

The 10 lucid dreams, in which the subjects tried to conduct the oddball task, were on average 143 seconds long and contained on average 54 non-target tones and 14 target tones. In eight lucid dreams, the subjects managed to respond to the target tones with eye signals. The hit rates (correctly responded target tones divided by the total number of target tones) lay between 27% and 100% for the individual lucid dreams. In five of the 10 lucid dreams, the subjects responded also to the non-target tones (hit rates between 1% and 8%). Viewing the average performance over all lucid dreams for each subject separately, the hit rates for the target tones were 71%, 35%, 27%, and for the non-target tones 0.5%, 3%, 3%. The task was never conducted by the subjects subconsciously during non-lucid REM sleep. During wakefulness, the oddball task was conducted by all subjects nearly perfectly (hit rates > 98 % for the target stimuli and < 0.5 % for the non-target stimuli).

The subjects were further asked whether they heard the tones only after concentrating on the task or already before. In seven of the 10 lucid dreams, the subjects noticed the tones only when concentrating on them, in two lucid dreams already before, and in one lucid dream the memory was unclear.

2.3.3 Evoked potentials

For calculating the evoked potentials, only two subjects supplied enough data of sufficient quality (in the one case with 42 target tone EEG epochs, and in the other case with 56 epochs).

During wakefulness, as to be expected, a clear P300 signal could be detected in both subjects. The latencies were 319 ± 28 ms and 339 ± 39 ms. During non-lucid REM sleep, only less clear P300 patterns were visible (especially in one of the two subjects), with latencies of 350 ± 32 ms and

391 ± 22 ms. During lucid REM sleep, the P300 EEG pattern of the correctly signaled target stimuli showed a similar morphology as the ones during wakefulness, and were clearly visible for one of the two subjects, and less clear for the second subject (it must be noted that this subject also showed a less clear P300 signal during wakefulness and REM sleep). During lucid REM sleep, the latencies were 323 ms and 297 ms (as only a grand average was computed for this condition, no standard deviation is reported). The amplitudes of the lucid REM sleep P300 patterns were in both subjects much smaller than during wakefulness, comparable to the P300 during non-lucid REM sleep. For one subject, enough data was available to analyze the lucid dreaming EEG signal of those target stimuli which were missed and not reacted to via eye movement during the lucid dream. For these stimuli, no P300 peak could be found.

2.4. Discussion

In this study, Strelen showed that it is possible for a lucidly dreaming subject to consciously discriminate between two auditory stimuli of an oddball paradigm, which were presented in a random order during sleep. For this, six lucid dreaming experienced subjects underwent polysomnographic recordings in the sleep laboratory, and were instructed to react to the target stimulus (a short 2000 Hz sine wave tone) with a simple pre-defined eye movement to the left and right. Three of the six subjects were able to conduct the given task during their lucid dreams. All of them were able to send eye signals to the target stimuli with worse performance than during wakefulness, but significantly better performance than what would be expected by chance.

The analysis of the P300 EEG patterns suggests that the cognitive information processing capabilities of lucid dreamers tend to be more similar to awake subjects than to non-lucid REM sleep subjects. For two subjects, sufficient data was available to compare the P300 evoked potentials for the lucid dreaming state, non-lucid REM sleep and wakefulness. The morphology of the P300 EEG pattern for the correctly answered target stimuli during lucid dreaming was similar to the P300 EEG pattern during wakefulness. A clear P300 peak was visible in one of the two subjects, in the other one, a less clear P300 peak was visible. The latency of the clear P300 EEG pattern was similar to the one during wakefulness, for the other case, it was slightly shorter. The amplitudes of the P300 peaks were in both cases much smaller than during wakefulness, and comparable to the ones during non-lucid REM sleep of the same subjects. For one subject, enough data was available to analyze the lucid dreaming EEG signal of those target stimuli which were missed and not reacted to via eye movements during the lucid dream. For these stimuli, no P300 peak could be found.

3. Remarks on Strelen's study

Strelen's experiment extends the knowledge of lucid dreaming regarding the interaction with the waking world, as well as the knowledge of the underlying neuroscientific processes of this phenomenon. As Strelen points out himself, his study builds on previous research: It was already known that external stimuli are sometimes incorporated into dreams (Schredl, 1999); that sleeping subjects can react subconsciously to external stimuli (Harsh and Badia, 1990); that a similar discriminative information processing takes place during REM sleep as during wakefulness, as suggested by the analysis of auditory evoked potentials (Niiyama et al., 1994, Bastuji et al., 1995); and that lucid dreamers are able to conduct given tasks within their lucid dreams (e. g. Hearne, 1978, LaBerge, 1980). In a case study, a lucidly dreaming subject was able to react to external stimuli (electric shocks) with muscle contractions, however, by initiating the stimuli himself (Fenwick et al., 1984).

As is unfortunately the case for many lucid dreaming studies, Strelen's experiment also suffers from a very low subject count. Only three subjects had verified lucid dreams during the experiment, and only two subjects delivered sufficient data for an evoked potential analysis of the EEG data. As a result, this experiment can only be regarded as a case study. Thus, the results must be treated cautiously, as Strelen himself also suggests in his dissertation.

Since 2006, when this dissertation was handed in at the Johannes Gutenberg University, Mainz, Germany, other lucid dreaming research has extended Strelen's experiments. For example, in an experiment by the author of this summary, it could be shown that even transferring a meaningful message (a random math problem) using Morse code into the dream, and answering to it using Morse-coded eye movements, is possible (Appel, 2013).

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