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Inducing lucid dreams by olfactory-cued reactivation of reality testing during early-morning sleep: A proof of concept

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ABSTRACT

The reliable induction of lucid dreams is a challenge in lucid dream research. In a previous study by our research group we were able to induce in about 50% of the participants a lucid dream in a single sleep laboratory night by combining a wake-up-back-to-bed sleep protocol and a mnemonic technique. In the present study, we extended our previous procedure by additional presentation of an odor during sleep to reactivate memory traces about reality testing. In total 16 male participants spent a single night in the sleep lab whereas the procedure induced in two participants a lucid dream (12.5%). The induction rate stays below the success rate of our previous study and therefore odor-cueing seems *not* a promising technique for inducing lucid dreams. Beside the odor presentation, several other methodological changes have been made, which will be discussed and hopefully help further dream engineering to improve induction techniques.

1. Introduction

A lucid dream is a dream during which the dreamer is aware of the fact that he or she is dreaming and therefore often can consciously influence the dream content (LaBerge, 1985). Proficient lucid dreamers can perform pre-arranged eye movements in their dreams and can carry out complex actions, therefore, sleep laboratory research with lucid dreamers opened the possibilities to study psychophysiological correlations from dreamed and real actions (Erlacher & Schredl, 2008). The main problem for research in this field is that skilled lucid dreamers are rare. A representative German survey showed that about 50% of the general population had at least one lucid dream experience in their life, about 20% of individuals experienced lucid dreams on a regular basis (once a month or more frequently), yet only 1% were having lucid dreams several times a week (Schredl & Erlacher, 2011). However, since the onset of lucid dream research, it was demonstrated that lucid dreaming is learnable and it is possible to increase the frequency of lucid dreams via certain induction methods (Stumbrys & Erlacher, 2014). In a review by Stumbrys, Erlacher, Schädlich, and Schredl (2012) different methods to induce lucid dreams have been identified. Even though there is evidence for the effectiveness of different techniques, like Mnemonic Induction of Lucid Dreams (MILD), Reflection or Reality Testing, or external light stimuli, the success rate of most studies is relatively small (Stumbrys et al., 2012).

MILD was developed by LaBerge (1985) and is based on prospective memory (Kliegel, McDaniel, & Einstein, 2008), e.g. the ability to remember intended actions performed in the future. LaBerge (1980) used a mnemonic device (a memory aid) for the MILD technique where a mental connection is made between a planned action and future circumstance in which the intended action is performed, e.g. by visualizing oneself doing what it is intended to remember (e.g. next time I'm dreaming I want to remember I'm

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dreaming).

A very promising approach is to combine MILD with the so called wake-up-back-to-bed sleep protocol (WBTB). The protocol is simple: The participant is sleeping for about 6 h, after waking-up the dreamer does the MILD technique with a remembered dream from the REM awakening or a previously remembered dream for about one hour, e.g., to identify dream signs and to visualize becoming lucid by repeating mentally the sentence: Next time I'm dreaming I want to remember I'm dreaming. After this period, the dreamer goes back to sleep for another two or three hours. The success rates in field studies (Edelstein & LaBerge, 1992; LaBerge, Phillips, & Levitan, 1994; Levitan, 1991; Levitan, LaBerge, & Dole, 1992) ranged from about 30% to 60% (with respect to the total number of dreams reported – not participants), considerably more effective than other techniques. However, the methodological quality of these field studies – evaluated with the quality checklist developed by Downs and Black (1998) – is relatively poor (Stumbrys et al., 2012). Therefore, laboratory studies using WBTB seems very promising because of two reasons: First, the sleeper can be awakened from REM sleep with a very high chance of dream recall (Nielsen, 2000), and secondly the one-hour wakefulness can be standardized and controlled by the experimenter. In a series of studies, applying the combination of WBTB and MILD, induced in about 50% of the participants a lucid dream in a single sleep laboratory night (Erlacher & Stumbrys, 2020) and therefore demonstrates that lucid dreams can be effectively induced in people who are not selected for their lucid dream abilities.

Research has demonstrated that one important function of sleep is memory consolidation (Rasch & Born, 2013). Animal research (e.g. Wilson & McNaughton, 1994) and research in humans (e.g. Rasch, Büchel, Gais, & Born, 2007) showed that sleep-dependent memory consolidation involves some form of replay of the learned task during sleep. There is evidence that cueing the task-related material by applying external stimuli during sleep can enhance performance (Rasch et al., 2007), i.e., presenting the odor during slow wave sleep that had been also presented during the acquisition period in waking had a beneficial effect on recall. Schredl, Hoffmann, Sommer, and Stuck (2014) presented two picture series (urban and rural setting) with two different odors (cross-over design) in waking and presented the odors during REM sleep. For the rural setting, a significant effect was found, i.e., topics of the pictures were more often present if the sleeper was stimulated by the same odor that was present during the learning session. For the urban setting, however, the effect was not found.

In the context of lucid dream induction, it is an open question whether pairing an odor during the induction technique (e.g. MILD) of the WBTB-paradigm helps to achieve lucidity in the second part of the night. The idea is that the odor presentation during the REM sleep of the morning nap causes an olfactory-cued reactivation of the previously acquired prospective memory of reality testing. Therefore, we expect an even higher induction rate of lucid dreams (> 50%) by combining these two methods.

2. Methods

2.1. Participants

16 male sports science students (age: 20.9 ± 1.5 years) participated in the sleep laboratory study and received course credit in return. The participants recalled on average 9.0 (± 10.3) dreams per month. One participant experienced lucid dreams "about once a week", two "about 2 to 4 times a year", two "about once a year", seven "less than once a year" and four "never" (mean: 0.3 ± 1.0 lucid dreams per months). We included only male participants to avoid gender constellation bias in the sleep laboratory setting because we had a male experimenter (Schredl, 2018). They provided written informed consent before the beginning of the study, which was approved by the ethics committee of the university faculty. The experiment was conducted in accordance with the Declaration of Helsinki.

2.2. Dream recall and lucid dream recall frequency

The participants filled out the Mannheim Dream questionnaire (MADRE; Schredl, Berres, Klingauf, Schellhaas, & Göritz, 2014). Within this questionnaire, dream recall frequency was measured by a 7-point scale ranging from 0 = *never* to 6 = *almost every morning*. Its retest reliability is high (r = 0.85; Schredl, 2004). The scale was recoded by class means to obtain units of mornings per month (*0* = 0, *1* = 0.5, *2* = 1.0, *3* = 2.5, *4* = 4.0, *5* = 14.0, *6* = 26.0). Furthermore, lucid dream frequency was measured on an eight-point scale ranging from 0 = *never* to 7 = *several times a week*. Again, the scale was recoded to units of mornings per month (*0* = 0, *1* = 0.042, *2* = 0.083, *3* = 0.25, *4* = 1.0, *5* = 2.5, *6* = 4.0, *7* = 18.0). Re-test reliability for the scale was found to be high ($r = 0.89$; $p < .001$; $N = 93$; Stumbrys, Erlacher, & Schredl, 2013a). In the MADRE a short definition is provided to ensure a clear understanding of lucid dreaming: "In lucid dreams, one has awareness that one is dreaming during the dream. Thus it is possible to wake up deliberately, or to influence the action of the dream actively, or to observe the course of the dream passively". The importance of a clear definition was originally discussed by Snyder and Gackenbach (1988). The different phenomenological aspects of lucid dreaming within the provided definition was studied by Stumbrys, Erlacher, Johnson, and Schredl (2014) and Stumbrys, Erlacher, and Malinowski (2015).

2.3. Polysomnography

Polysomnography (PSG) was conducted to register sleep stages. PSG recording included electroencephalogram (EEG: F3, F4, C3, C4, O2, O1), electroocculogram (EOG), submental electromyogram (EMG) and electrocardiogram (ECG). EEG electrodes were placed according to the international Ten-Twenty system (Jasper, 1958). A standard recording device (XLTEK Trex Longtime EEG recorder) recorded sleep data with a DC amplifier and sampled at 250 Hz. Sleep stages were manually scored according to the AASM criteria

(Iber, Ancoli-Israel, Chesson, & Quan, 2007).

2.4. Odor delivery and substance

The experimental odor was delivered via a computer-controlled olfactometer as described in Rasch et al. (2007). The olfactometer was placed in a separate room and was connected to the participant's mask via Teflon tubes, which allowed odor stimulation to be regulated without disturbing the participant. The odor was delivered via a small nasal mask that assured constant stimulation but permitted normal breathing. The experimental odor was isobutyraldehyde (≥99%) diluted in 1,2-propanediol at a concentration of 1:200 (IBA; Sigma-Aldrich, Munich, Germany; similarly used in Diekelmann, Büchel, Born, & Rasch, 2011).

The odor detection test, performed before the experiment, required participants to indicate the presence or absence of the experimental odor stimulus on 10 trials. The percentage of correct responses was on average 93.8% ± 9.3%.

Participants underwent on average 30.8 ± 3.7 odor stimulations during the two Reflection/reality testing sessions in wakefulness and 33.6 ± 10.1 odor stimulations during REM sleep. For the REM sleep stimulations, the experimenter checked the online EEG recordings for REM criteria. In cases of spontaneous awakenings the experimenter stopped further stimulation and asked the participants for a dream report (see procedure).

2.5. Reflection/reality testing

The reflection technique was first described by Tholey (1982). In this original German paper Tholey developed a 10-step-instruction to induce lucid dreams. The aim of this technique is as follows: “If a subject develops while awake a critical-reflective attitude toward his momentary state of consciousness by asking himself if he is dreaming or not, then this attitude can be transferred to the dream state.” (Tholey, 1983, p. 80). To gain this critical-reflective attitude it is important to critical question the state of consciousness which is also known as reality testing, which involves asking oneself regularly during the day whether one is dreaming or not, and examining the environment for possible incongruences (Tholey, 1983).

2.6. Procedure

The participants spent a single night in a dark and quiet room at the Institute of Sport Science (University of Bern) with continuous PSG recording. They arrived at 9:00 pm and the experimenter familiarized them with the room and setting. Then, the participants prepared themselves for the night and all electrodes were attached by the experimenter. After the recording signals were checked, the experimenter explained the participants the definition of a lucid dream and trained them in left–right-left–right eye movements (LRLR) to signal a possible lucid dream (LaBerge, Nagel, Dement, & Zarcone, 1981). The LRLR signal was trained in front of the recording screen to give feedback to the participants and to ensure that they move their eyes all the way to the left and then to

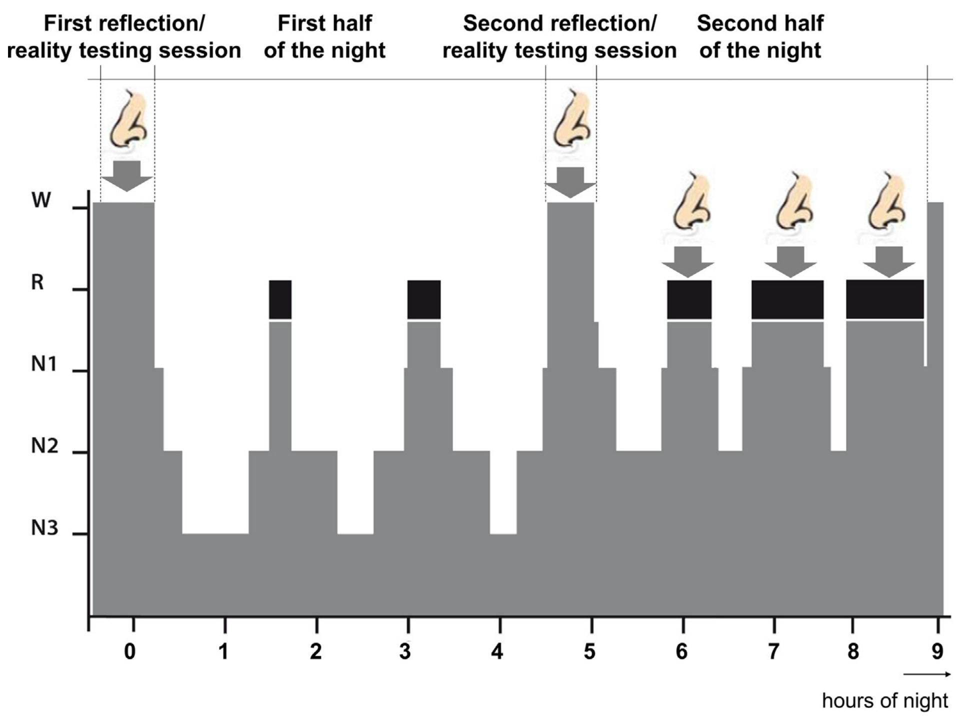

Fig. 1. The night procedure divided into four parts.

the right through a continuous movement without pausing (standardization of LRLR, see Mota-Rolim, 2020). The participants were also instructed about the awakening after about 4.5 h of sleep (see below). The night procedure was divided into four parts (see Fig. 1).

1. First reflection/reality testing session with odor. On average at 10:14 pm (± 10 min), the first reflection/reality testing session started – depending on the time needed for the previous procedure (e.g. attaching electrodes). Participants had to read a German text about lucid dreaming written by Tholey (1982) including a 10 steps instruction on how to achieve lucidity by the reflection technique (see reflection/reality testing). The reading duration was between 11 and 20 min. While reading every 30 s a specific odor was presented via an olfactometer. The odor presentation followed an alternating pattern of 30-seconds on/30-seconds off phases to reduce habituation as described by Rasch et al. (2007).
2. First part of the night. On average at 10:33 pm (± 10 min), the first part of the night started with "lights off" – depending on the reading time and bed procedure (e.g. going to restroom). Participants went to sleep and after 4.5 h of uninterrupted sleep (a rough estimate of 3 REM periods) participants were awakened, regardless the sleep stage. Via intercom system, the participants were called by their name until they responded. Then, they were asked to report any mental content that was in their mind before awakening. If the participant did not recall any sleep mentation immediately, he or she was given 2 min to think about it and try to recall it. Further, the participants were asked if in the dream they were aware that they were dreaming and if they gave a LRLR eye-signal. All conversation was recorded via a voice recorder.
3. Second reflection/reality testing session with odor. On average at 3:11 am (± 5 min), the participants were awakened for the second reflection/reality testing session. The session was divided into three parts (about 10 min each): (1) Continue reading the text by Tholey (1982), (2) introduction to reality testing whereas four common reality tests were described in detail (e.g. try breathing while closing you airways), (3) practicing reality tests. The reflection/reality testing session lasted between 10 and 18 min whereas the total wake time was 25 min (± 6 min). During the session again every 30 s a specific odor was presented via an olfactometer.
4. Second part of the night with odor. On average at 3:36 am (± 7 min), the second part of the night started with "lights off" – depending on the session duration and final bed procedure (e.g. going to restroom). Participants went back to sleep for the second half of the night. During all following REM periods, the odor was presented with the same alternating pattern of 30-seconds on/30-seconds off phases. The odor stimulation was continued until the participants woke up by themselves or the REM sleep period ended. In the second case, the experimenter awaked the participants. In both cases, the experimenter asked for a dream report via intercom system (see above). After a maximum of 4.5 h of morning sleep, the study night ended.

All recorded dream reports were transcribed, randomly permutated and scored by a blinded judge for lucidity on a 3-point scale (0 – no evidence of a lucid dream, 1 – possible indications of a lucid dream, 2 – clear indication of a lucid dream), which was shown to have a good interrater agreement ($r = 0.86$; Stumbrys, Erlacher, & Schredl, 2013b). Furthermore, the judge also rated the dream reports about sensory sensation like smell, taste and touch.

2.7. Criterion for successful lucid dream induction

Three types of proofs were used to establish successful induction of a lucid dream: (1) self-rating of lucidity, (2) assessment of the dream report by an external judge (3) LRLR eye signals on the sleep recording during REM, which was reported by the participants. For the "strict" criterion, the induction is considered successful if: (1) the participant reports a lucid dream; (2) the judge rated this dream report either with clear or possible indications of lucidity; (3) the participant reported LRLR eye signaling and the eye signal can be unambiguously identified on the sleep recording during REM sleep. For the loose criterion, (1) and (2) were considered as sufficient.

2.8. Statistical analysis

Because this was an exploratory study, the main focus is on descriptive statistics. IBM SPSS Statistics 20 software was used for the descriptive statistical analysis.

3. Results

3.1. Sleep data

The sleep data for the first and second part of the night is provided in Table 1. As expected the slow wave sleep is more pronounced in the first half of the night (26.9% vs. 3.1%) whereas REM sleep is higher in the second half of the night (10.2% vs. 20.9%). All participant were able to fall asleep after the WBTB procedure. The average WBTB sleep latency was 31.5 ± 26.0 min. For the second part of the night, 8 participants had 2 and the other 8 participants had 3 REM sleep periods in with an average latency of 42.1 ± 24.7 min to the first REM period after sleep onset and a total REM sleep duration of 44.2 ± 18.1 min. During these 40 REM sleep periods the experimenter presented the odor on average for 33.6 ± 10.1 times.

Table 1
Sleep data of the first and second half of the night.

	First half of the night	Second half of the night	*t*-test	
	n = 16	n = 16	*t*	*p*
Total bed time (min)	276.4 ± 9.9	215.8 ± 37.7	6.05	< 0.001
Total sleep time (min)	246.6 ± 14.0	187.0 ± 31.4	6.57	< 0.001
Sleep efficiency (%)	89.2 ± 4.9	87.0 ± 6.5	1.39	0.184
Sleep latency (min)	11.0 ± 8.7	7.4 ± 6.2	1.74	0.102
REM latency (min)	124.3 ± 44.9	55.7 ± 32.4	5.10	< 0.001
REM period count	2.0 ± 0.5	3.1 ± 0.9	−4.58	< 0.001
REM period range	1–3	2–4		
REM total time (min)	28.3 ± 11.0	44.2 ± 18.1	−3.04	0.008
REM % SPT	10.2 ± 3.9	20.9 ± 8.3	−5.10	< 0.001
Wake % SPT	10.8 ± 4.9	13.0 ± 6.5	−1.40	0.183
Stage 1% SPT	3.4 ± 1.5	5.3 ± 2.2	−3.64	0.002
Stage 2% SPT	48.7 ± 6.9	57.8 ± 8.3	−3.69	0.002
Stage 3% SPT	26.9 ± 8.1	3.1 ± 4.3	9.74	< 0.001

3.2. Dream reports

In total, 40 dream reports were provided from the experimental night: 10 from the first half of the night and 30 from the second half of the night. From those 30 dream reports 10 (out of 16) were reported from the first, 14 (out of 16) from the second and 6 (out of 8) from the third REM sleep period of the second part of the night – on 10 occasions (25%) no dreams were recalled. The dream reports had an average length of 75.2 ± 51.1 words.

3.3. Induction of lucid dreams

(1) Self rating. In total, 2 out of 16 participants reported a lucid dream during the second half of the night with additional odor presentation (12.5%). In 1 occasion, a participant was unsure about whether he experienced a lucid dream or not. Furthermore, 1 participant experienced a lucid dream in the first part of the night (6.3%).
(2) External judge. The judge rated 37 dream reports as without evidence of lucid dreaming (exactly the same ones as the dreamers themselves), 3 dream reports as with clear indications of lucid dreaming. The dream report, which was rated by a participant as ambiguously lucid, was scored as non-lucid by the external judge.
(3) LRLR eye signal. Finally, on 2 occasions, the participants reported that they were unsure if they produced a LRLR eye signal. In none of the 2 cases a prearranged eye-signaling was observed in the sleep recording.

3.4. Incorporation of odor in dream report

In 1 occasion, a participant reported the odor perception in the dream, which also led to lucidity. The presence of the odor was verified by the external rating of the dream report. In the remaining 39 dream reports no odor was reported either in the self ratings nor by the external judge.

4. Discussion

The findings of the present study show that the combination of WBTB and odor-cued reality testing is not as effective as single previously reported lucid dream induction method with WBTB and MILD techniques (Erlacher & Stumbrys, 2020). The low induction rate in this study could be explained by the fact that odor-cueing is not a promising technique for inducing lucid dreams. However, several methodological changes have been made in this study compared to our previous work with higher induction rates and therefore those changes should be discussed in the first place.

Firstly, the sleep duration in the first half of the night was shortened from previously 6 to 4.5 h of sleep. This change of sleep duration in the first half of the night could lead to circadian and homeostatic differences. In a yet unpublished sleep laboratory study by our research group we applied a sleep interruption after 4.5 h in combination with MILD which lead to reduced lucid dream induction rates (14.3%). One possible explanation might be that REM sleep is less pronounced in the second half of the night if the sleep interruption follows after 4.5 instead of 6 h of sleep. However, in this study the second half of the night showed short REM latencies and long REM durations (see Table 1) and therefore this explanation seems rather unlikely. Furthermore, due to the earlier sleep interruption it might be that sleep pressure is still high in the second half of the night. Indeed, participants in this study showed very good sleep efficiency for the second half of the night, whereas in the study by Erlacher and Stumbrys (2020) reported sleep efficiencies was between 66 and 83 percentage and one of the participants could not fall asleep at all. Some authors speculate that lighter sleep has a benefitting effect on lucid dream induction (Gackenbach & LaBerge, 1988) and therefore might explain the lower induction rate in the study at hand. However, the relationship between lighter sleep and lucidity seems to be rather optimal than linear, e.g. in cases where participants cannot sleep at all or do not show REM sleep after WBTB the procedure is obviously detrimental to lucid dream induction. In any case, the underlying mechanisms that cause lighter sleep (e.g. hormonal factors) and why this should promote lucidity are unclear and further research is needed.

Secondly, the induction session had been modified from a MILD procedure (LaBerge, 1985) to reflection/reality testing technique (Tholey, 1982). Both techniques rely on prospective memory but differ in their instructions. The differences in the induction session might have unfavorable effects on lucid dream induction rate. This is underlined by a yet unpublished study by our research group in which we combined WBTB and reality testing leading to three out of 15 participants (20%) experiencing a lucid dream in a single sleep laboratory night. Nevertheless, systematic research on the content and effectiveness of different cognitive procedure like MILD or reality testing is scarce (Stumbrys, Schädlich, & Erlacher, 2019).

Thirdly, the time spent performing reflection/reality testing was shortened from 60 to 30 min compared to our previous study Erlacher and Stumbrys (2020). The duration of WBTB period seems to be an important factor in the effectiveness of the technique. This assumption is supported by the results from our research where the induction rate dropped from 50% to 35% when using a MILD design and shortening the nightly interruption from 60 to 30 min (Erlacher & Stumbrys, 2020). Moreover, the shorter odor intervention could potentially lead to a weaker association between the odor and the prospective memory about reality testing. To prolong the duration of the reflection/reality testing session with odor presentation, thus seems a promising variation for future studies.

Interestingly, arbitrary results on the effectiveness of odor cueing during REM sleep are found. Some authors found targeted memory reactivation during REM sleep to be effective and found a heightened rate of the incorporation of rural scenes into dreams (Schredl, Hoffmann, et al., 2014). Contrary to these findings, other authors could not find a relationship between targeted memory reactivation where no stabilizing effect was found on odor-induced memory when the reactivation happened during REM sleep (Cordi, Diekelmann, Born, & Rasch, 2014; Rasch et al., 2007). Beside that, the odor cueing should modified in a systematic manner. Future studies for example could present olfactory stimuli during sleep with or without arousing the participants (Stuck et al., 2007) or different odors which are pleasant or unpleasant (Rihm, Diekelmann, Born, & Rasch, 2014).

Two recent studies applied an acoustic cue during the induction technique of the WBTB-paradigm. In the study by Carr et al. (2020) lucid dreams were successfully induced in a single laboratory nap session by pairing cognitive training with beeping tones. The session was in the morning either at 7:30 am or 11:00 am and the duration was 20 min. The results showed that 50% of the cued participants produced a signal-verified lucid dream. In contrast, Schmid and Erlacher (2020) combined music (e.g. “Non, je ne regrette rien” by Édith Piaf) with reality testing. The 1 h session was also embedded in a WBTB-protocol at 4.5 h after sleep onset (same as in this study), but only 14% of the participants become lucid and none of those lucid dreams were verified by LRLR eye signal. Thus, it seems that not the duration of the session but the hours of previous sleep might be more important to induce lucid dreams successfully.

The success rates in this study is quite low, compared to our sleep laboratory study inducing lucid dream with WBTB and MILD alone (Erlacher & Stumbrys, 2020) and therefore we did not apply a methodological scrutiny e.g. conditions where a vehicle is presented. If future studies will find higher lucid dream rates by odor-cued variations, those studies would have to run different control conditions to adequately test their hypotheses (e.g. Rasch et al., 2007). A final methodological limitation, that needs to be addressed in future sleep lab research, is the proper validation of lucid dream by LRLR eye signals because during a night recording, participants might shows hundreds of eye movements during (REM) sleep; and therefore a high probability exists to find by chance a LRLR. One methodological approach would be to compare each LRLR sequence against the probability to find it by chance. Since no signal verified lucid dream was induced in this study, this empirical evaluation has not been carried out in this study but is recommend for future lab research in lucid dream induction research.

To summarize, the present study combined the so-called wake-up-back-to-bed sleep protocol (WBTB), reality testing and odor-cueing to induce lucid dreams. From 16 participants the procedure induced in 2 participants a lucid dream (12.5%) whereas none of those lucid dreams was verified by LRLR eye signal. The success rate of a combination of odor-cueing with reality testing thus lies behind the success rate of other induction techniques. Future studies should focus on the raised methodological factors and their influence on lucid dream induction.

CRediT authorship contribution statement

Daniel Erlacher: Conceptualization, Methodology, Validation, Formal analysis, Data curation, Writing - original draft, Visualization, Supervision. **Daniel Schmid:** Validation, Data curation, Writing - review & editing. **Silvan Schuler:** Investigation, Writing - review & editing. **Björn Rasch:** Conceptualization, Methodology, Resources, Software.

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