Combining pre-sleep cognitive training and REM-sleep stimulation in a laboratory morning nap for lucid dream induction

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All data will be made available on request.

Abstract

Previous experiments combining cognitive techniques and sleep disruption have been relatively successful in inducing at-home lucid dreams over training periods of 1-week or more. Here, we induce lucid dreams in a single laboratory nap session by pairing cognitive training with external stimulation. Participants came to the laboratory at 7:30 am or 11:00 am and during polysomnography setup were provided with information about lucid dreaming. For twenty minutes prior to sleep the experimenter played alternating audio and visual cues at 1-minute intervals. Participants were instructed to practice a mental state of critical self-awareness, observing their thoughts and experiences each time they noticed a cue. This procedure associated the cues with the trained mental state. Subsequently, participants were allowed 90 minutes to nap, and the audio and visual cues were re-presented during REM sleep to activate self-awareness in dreams and elicit lucidity. A control group followed the same procedure but was not cued during sleep. All participants were instructed to signal their lucidity by looking left and right four times (LR Signal). Signal-verified lucid dreams (SVLDs) qualified as dreams in which the LR signal was observed and the participant reported becoming lucid. Across the two nap times, this protocol induced SVLDs in 50% of participants. In the absence of cueing during sleep, participant SVLD rate was 17%. Of note, three successful participants had never before experienced a lucid dream, suggesting this protocol may be effective across the general population. Implications of this Targeted Lucidity Reactivation protocol for nightmare treatment are discussed.

Keywords: Lucid dreaming; REM sleep; Sensory Stimulation; Nightmares; Targeted Lucidity Reactivation

Introduction

A lucid dream (LD) is one in which the dreamer is aware that they are dreaming while asleep (Baird, Mota-Rolim, & Dresler, 2019; LaBerge, Levitan, & Dement, 1986). While LDs are prevalent in the population (i.e., *across* individuals), they do not re-occur *within* individuals frequently (Mota-Rolim et al., 2013). Because of this, it is difficult to predict when a LD will occur in the laboratory. To increase chances of recording verifiable LDs in the laboratory, many studies have targeted recruitment of only frequent lucid dreaming participants, but this restricts applications and generalizability of LD research, and moreover recruiting frequent LD participants still does not guarantee successful induction. Thus, a major area of current research is to develop and refine methods to induce LDs with high reliability in the laboratory (Appel, Pipa, & Dresler, 2018; Stumbrys, Erlacher, Schädlich, & Schredl, 2012). Furthermore, clinical applications of lucid dreaming, for example nightmare treatment (Gieselmann et al., 2019), are hindered by an inability to reliably induce LDs (Payne, 2014), and thus solving the "induction problem" is crucial to implementing such approaches.

In general, current LD induction methods can involve cognitive strategies, sleeping behavior strategies, external stimulation, and other miscellaneous categories (Price & Cohen, 1988; Stumbrys et al., 2012). A common cognitive technique is the reality check, where participants reflect on the question, "Am I dreaming?" several times throughout the day. This cognitive habit can transfer into dreams and trigger the realization that one is dreaming (Tholey, 1983). A second cognitive technique, the Mnemonic Induction of Lucid Dreams (MILD; (LaBerge, 1980), utilizes the period immediately before bed to prime lucidity; this technique involves setting the intention to become lucid and repeating a phrase in mind prior to falling

asleep, such as “The next time I am dreaming I will remember that I am dreaming.” Both reality checking and MILD rely on metacognition, by drawing awareness to one's current cognitive state, and prospective memory, by registering one's intention to remember something in the future. In line with these techniques, lucid dreaming frequency positively correlates with need for cognition, internal locus of control (Blagrove & Hartnell, 2000), and mindfulness (Baird, Riedner, Boly, Davidson, & Tononi, 2019; Stumbrys & Erlacher, 2017; Stumbrys, Erlacher, & Malinowski, 2015). Although Baird, Riedner, et al. (2019) found that an 8-week mindfulness course did not increase lucid dreaming frequency, other work has shown middle-of-the-night meditation in combination with imagery techniques (Sparrow, Thurston, & Carlson, 2013) and pharmacological supplements (Sparrow, Hurd, Carlson, & Molina, 2018) augments dream lucidity. Nevertheless, it has not yet been studied whether mindfulness could be combined with MILD and reality checking in order to induce lucid dreams in the laboratory.

Modifying sleep is another approach for inducing lucid dreams. The best-known sleep modification technique is the Wake-Back-To-Bed (WBTB) method, wherein one wakes up for 10-60 minutes before returning to sleep. A few studies suggest that there may be an optimal window for combining early awakenings with a morning nap, longer awake intervals having higher success rates (e.g., 60 vs 10 minutes; LaBerge, Phillips, & Levitan, 1994). Up to 2 hours of wakefulness prior to a morning nap seems to be more effective than 4 hours of wakefulness (Levitan, 1990), and more effective than an afternoon nap (Levitan et al., 1992). In a similar manner, studies have found that sleep disruption (Konkoly & Burke, 2019) and alarm clock snooze button use (Smith & Blagrove, 2015) are associated with LD frequency. The WBTB method may increase chances of lucidity by inducing sleep with more arousal than typical

nighttime sleep, as physiological arousal (e.g., REM density; LaBerge et al., 1986) has been associated with lucidity (Baird, Riedner, et al., 2019). It is also possible that increased REM propensity at the end of the night (Dijk & Czeisler, 1994) corresponds with a greater propensity to lucid dreaming at that time (Laberge, 1985). Support for this view includes that narcoleptics have higher LD frequency (Rak, Beitinger, Steiger, Schredl, & Dresler, 2015), which has been attributed to their minimal REM latency (Dodet, Chavez, Leu-Semenescu, Golmard, & Arnulf, 2015). More generally, time of night affects dreaming, with late morning dreams more frequently recalled and more vivid than early night dreams (Carr & Solomonova, 2019). Accordingly, a sleep period that maximizes dream recall and arousal, and minimizes REM latency would likely be ideal for LD induction.

External stimulation can influence dreaming in a variety of sensory modalities, though rates of incorporation into dreaming vary from 9% to 87% (Solomonova & Carr, 2019). In the past, visual and auditory stimulation have been utilized to trigger lucidity. For instance, the DreamLight studies (LaBerge, 1988; LaBerge & Levitan, 1995) used flashing red lights to cue sleeping participants, with the expectation that dreamers would notice the lights in their dreams and become lucid by realizing the cues came from the external world. Combining MILD with a light stimulating mask (the DreamLight) over the course of an 8-week period led to 20% of reported dreams being lucid (LaBerge, 1988). A second study found 88% of participants became lucid at least once in a 28-day span using MILD and the DreamLight, though the sample consisted of frequent lucid dreamers (LaBerge & Levitan, 1995). It was also found that, using acoustic stimulation, 31% of participants became lucid at least once over four nights of stimulation, but this after 3 weeks of training (Kueny, 1985). That these studies used variable

training periods, and quantify lucidity as a proportion of participants or dream reports that are lucid across many attempts, makes it difficult to predict success rates for any singular attempt. More recently, cueing has been studied in the laboratory; for example, visual stimulation led to lucidity in 5.6% of trials, and tactile stimulation in 7.4% of trials in a single laboratory overnight (Paul, Schädlich, & Erlacher, 2014). Thus, the use of external stimulation alone may not be the most reliable laboratory method for lucid dream induction.

In general, combining cognitive techniques, sleep disruption and external stimulation may be most effective for LD induction (Stumbrys & Erlacher, 2014; Stumbrys et al., 2012). Recently, a combination of daily reality checks, WBTB, and MILD was associated with LD recall in 53% of participants over the course of one week (Aspy, Delfabbro, Proeve, & Mohr, 2017). Appel (2013) found that WBTB utilizing a 20-30 minute wake interval and cue stimulation in subsequent REM sleep induced lucid dreams in 2 of 5 participants on the second experimental night. Another recent study had participants undergo cognitive training over a period of 3 months prior to coming to the laboratory for an overnight with audio stimulation during REM sleep; this protocol successfully induced lucid dreams in 5 of 6 participants (Kumar, Sasidharan, Nair, & Kutty, 2018). Schädlich, Erlacher, & Schredl (2017) recorded lucid dreams in 9 of 15 participants in one laboratory overnight, a 60% success rate in experienced lucid dreamers who recall at least 1 LD per month; their induction procedure involved a combination of WBTB, dream journaling during the wake interval, and instruction to perform reality checks if they noticed any laboratory elements in their dream.

In the current study we hoped to maximize LD induction success in the laboratory with a minimal experimental protocol that combined several techniques. To this aim, we developed a

protocol whereby cues are associated with a lucid mind-state during wakefulness, and are then re-presented during REM sleep to trigger lucidity. This technique parallels others in the broader domain of 'targeted reactivation' (Cellini & Capuozzo, 2018; Rasch, Büchel, Gais, & Born, 2007), in which associations are formed between cues and memory traces in waking life, and subsequently cues are re-presented during sleep to reactivate the associated memory. We devised the term 'Targeted Lucidity Reactivation' (TLR) for this protocol. Our first aim was to see whether early naps, which are more similar to typical WBTB, would be more effective than late morning naps for LD induction. Our second aim was to test whether cueing was more effective than not-cueing during REM sleep to induce lucidity.

Method

Participants

Forty-one participants aged 18-40 were recruited via fliers and the Psychology Department Participant Pool at Swansea University. The advertisement recruited participants for a lucid dreaming study, and in addition to general recruitment we also targeted recruitment efforts on individuals who recall bad dreams at least weekly, due to the implications of LDs for nightmare therapy. No history of lucid dreaming or prior knowledge of the topic was required. Participants were assigned to one of three groups: 7:30 am arrival time with cueing during REM sleep ('7:30 cued', N=14, 11 female, 20.86±2.71 years); 11:00 am arrival time with cueing during REM sleep ('11:00 cued', N=14, 10 female, 21.71±4.21 years); 11:00 am arrival time without cueing during REM sleep ('11:00 noncued', N=13; 9 female, 23.62±6.21 years).

General procedure

Participants came into the lab for a single morning session either at 7:30 am or 11:00 am (Figure 1). Following Informed Consent (ethics approved by the Research Ethics Committee of the Department of Psychology at Swansea University), participants were wired up for polysomnography (PSG) while experimenters defined lucid dreaming and explained the procedures of the experiment in detail. Following PSG setup, participants underwent a 20-minute training that involved associating alternating audio and visual cues to a state of critical self-awareness that was described by a verbal prompt. Following training, the participant was allowed up to 90 minutes to nap, during which the cues were re-played during REM sleep in the cued groups, but not the noncued group. Participants were awakened for dream reports collected via a semi-structured interview. At the end of the nap session, participants responded to 6 questionnaires prior to being debriefed and paid for their participation. From participant arrival to departure, the experiment took maximum 3 hours to complete.

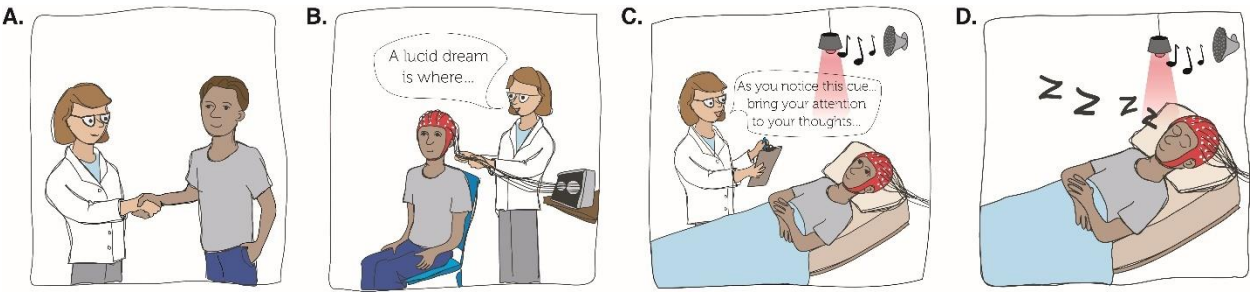

Figure 1. Targeted Lucidity Reactivation. A) Participants arrived at 7:30 or 11:00 am; B) each session began with simultaneous PSG setup and explanation of lucid dreaming. C) Participants then underwent a 20-minute training while lying awake in bed, with audio and visual cues used to prompt self-awareness. D) Participants had a 90-minute nap period during which cues were re-presented at REM sleep onset. A Control group followed the same procedure but without cues presented during the nap.

Cue levels and eye signal practice

The audio cue was a series of 500-700-900 Hz beeping tones (200ms on/off at each ascending frequency). The visual cue was a red LED light, flashed three times at an approximate rate of 500ms on/off. Sound and light levels for these were checked while the participant was lying in bed prior to training; the participant was instructed to indicate the audio level and brightness level at which they could easily notice the cue but felt it would not wake them up. Once the cue levels were adjusted, participants practiced the eye signaling procedure. Participants were instructed to visualize a recent dream and to imagine becoming lucid in the dream and signaling with eye movements by looking left and right quickly four times (LR Signal). Two audio and two visual cues were then played at intervals (audio cue, interval, visual cue, interval, audio cue, interval, visual cue) and participants practiced signaling each time they saw or heard a cue.

Targeted Lucidity Reactivation

For TLR training, the participant was read the following instructions:

"Now we are going to practice becoming lucid. We want to train your mind to recognize the flashing lights and beeping sounds as "lucidity cues" so that you can have a lucid dream. While you rest here, we are going to play the cues at approximate 1-minute intervals. Whenever you hear or see one of the cues, you should remain in the same position with your eyes closed, but you will ***become lucid*** *by attending to where your mind has been, attending to your body, and attending to your surroundings. Focus on how aspects of your experience might be in any way different from your normal waking*

experience. You do not need to do eye signals while awake, only do the signals when you become lucid in a dream."

During the next 5 minutes of this procedure, the audio and visual cues were played at approximate 1-minute intervals (audio cue, interval, visual cue, interval; this pattern is repeated throughout the study), and after each cue the following prompt was given:

"As you notice the cue, you become lucid. Bring your attention to your thoughts, notice how your mind has wandered…[pause]…Now observe your body, sensations, and feelings…[pause]…Observe your breathing...[pause]... remain critically aware, lucid, and notice how aspects of this experience are in any way different from your normal waking experience."

After the first 5 minutes, the experimenter continued to play audio and visual cues at approximate 1-minute intervals for 8 minutes, but without giving the prompt. The participant was instructed to continue to practice becoming lucid each time they saw or heard a cue by observing their thoughts, their body, and their feelings, and noticing how aspects of their experience differed in any way from normal waking experience. Finally, for 7 minutes, the cues were spaced out over longer intervals and the participant was told they could begin to fall asleep, but, nevertheless, to continue to try to become lucid each time they noticed a cue. They were also reminded that the cues would be re-presented during sleep, and if they became lucid during a dream to remember to signal with eye movements.

Nap period

Starting from the end of the training period, participants had a maximum 90-minute window to sleep. PSG data were collected from participants using either a Trackit™ 18/8 system

(version 2.7.7, Lifelines Ltd, UK) or a Traumschreiber sleep mask (Appel, 2018). Electroencephalography (EEG) placement followed the standard 10-20 system with sensors at F3/F4, a ground electrode placed on the forehead, and a reference at A1. Electrooculography (EOG) electrodes were applied above the right outer canthus and below the left outer canthus, with two additional electromyography (EMG) electrodes placed on the chin to monitor muscle tone. PSG data were scored offline using Polyman sleep scoring software (Kemp & Roessen, 2007). Although standard American Academy of Sleep Medicine guidelines require 3 derivations (Berry et al., 2012), we estimated sleep stages based on the available frontal electrodes. PSG was monitored online during the nap in order to deliver cues and prompt awakenings for dream reporting.

REM-sleep cueing

Cued groups. As soon as the participant entered phasic REM sleep (evidenced by the first eye movement), the experimenter played audio and visual cues alternating at approximately 15 seconds. However, if the cue presentation resulted in an arousal, the experimenter waited for arousal indications (e.g., muscle tension) to dissipate and then resumed playing cues. Participants were instructed to signal once they became lucid and each time they noticed a cue. If the LR signal was observable on the EOG trace at any time, the experimenter played cues until the dreamer stopped signaling in response to the cues, at which point they were awakened, or until the participant awoke on their own. If no LR signal was observed, the experimenter continued to play cues until an awakening occurred, or if no awakening occurred the experimenter triggered an awakening when the REM period ended.

Noncued group. The experimenter did not play cues during REM sleep, but triggered an awakening following approximately 5 minutes of REM sleep. If at any point during REM sleep an LR signal was observed on the EOG trace, the experimenter triggered an awakening for dream reporting to ensure the participant would recall their LD on awakening. As with the cued group, participants in the noncued group were instructed to signal once they became lucid and each time they noticed a cue, thus in the absence of cues they would not be prompted to signal more than once.

Dream Report

Immediately upon awakening, the participant completed a dream interview with the experimenter (via intercom) with specific questions to report their dream, respond whether they were lucid, whether they observed cues in the dream, and whether they gave the LR signal. The questions used were similar across study conditions although varied slightly between participants. Following dream reporting, if there was still time in the nap period, participants were allowed to go back to sleep and the procedure was repeated in the next observable REM period, or until the 90-minute nap period ended, at which point the participant was awakened.

Questionnaires

Following the final awakening, participants left the bedroom, PSG was removed, and they completed questionnaires. They first answered the LuCiD scale, designed to assess aspects of lucidity in dreams such as memory, insight, control, dissociation, and emotion (Voss, Schermelleh-Engel, Windt, Frenzel, & Hobson, 2013). Though participants ranged from reporting one to four different dreams, they were instructed to respond to the scale with

reference to their most lucid or vivid dream. The 'Insight' items refer to awareness of the fact that one is dreaming; the 'Thought' subscale assesses the amount of thinking the dreamer experiences; 'Memory' refers to remembering elements of waking life within the dream; 'Control' is the ability to control one's actions or environment in the dream; 'Dissociation' is a shift in perspective that involves seeing oneself from the outside or observing the dream from the 3rd-person; and 'Negative' and 'Positive' emotional content of the dream is assessed in the final two subscales.

Participants also completed self-report measures of typical dream recall and sleep schedule. This included responding to questions regarding bedtime and rise-time, both typically and for the night/morning preceding the laboratory visit. Participants also completed self-report measures of dream recall frequency for the past week, with separate open-ended questions for: 'How many times in the past week did you remember a neutral dream/bad dream/nightmare/positive dream on waking?' and 'Have you had any lucid dreams? If yes, how often?'. We asked participants to rate the impact of their dreams on waking mood: 'Please rate the waking distress caused by your bad dreams/nightmares on a scale of 1 to 9' and 'Please rate how much your positive dreams impact your waking mood on a scale of 1 to 9'.

Participants then completed 5 personality measures. The Typical Dreams Questionnaire, a measure of dream theme diversity (Griffith, 1950; Nielsen, 2012; Nielsen et al., 2003), is a 56-item questionnaire where participants tick any of the 56 types of dreams they have experienced. The Mirror Behaviors Questionnaire (Nielsen & Kuiken, 2013) is an 18-item questionnaire with items on a 4-point Likert scale that measure tendencies to mirror the actions and expressions of others and may generally relate to a sensitivity to behavioral signals

from others. The Highly Sensitive Person scale (Aron & Aron, 1997) assesses sensitivity to sensory stimuli during wakefulness, which could influence sensory sensitivity during sleep; this is a 27-item questionnaire with responses on a 7-point Likert scale designed to measure perceptual and emotional sensitivity. The Boundary Personality Questionnaire has been related to dream recall frequency and consists of a 20-item questionnaire measuring sensitivity and intra-psychic rigidity/fluidity with responses on a 5-point Likert scale (Harrison, Hartmann, & Bevis, 2006; Schredl, Bocklage, Engelhardt, & Mingebach, 2009). Finally, the reduced Morningness-Eveningness Chronotype Scale (Adan & Almirall, 1991; Horne & Östberg, 1976) is a 5-item questionnaire designed to assess daily sleep/wake patterns.

Analysis

Analyses were conducted with Statistica software (version 10, Statsoft); all tests use a 2-sided significance level of $p<.05$.

Sleep measures. Participants' self-reported bedtime and rise-time the night preceding the laboratory visit were used to calculate sleep duration and wake interval between morning rise-time and laboratory nap onset; sleep duration and wake interval were compared between groups using ANOVA. We also calculated minutes of Stage N1, N2, N3 and REM sleep in the laboratory nap and compared these values between groups (ANOVA).

LD induction rates. A dream was classified as a signal-verified lucid dream (SVLD) if the participant reported lucidity upon awakening, and the LR signal was observed prior to awakening. All other dreams were classified as nonSVLD. We then coded each participant as a single value of either SVLD or nonSVLD, where SVLD denoted the participant had at least one SVLD during their nap session. Two 2x2 contingency tables of group combinations (7:30 am

cued vs 11:00 am cued; cued vs noncued) by dream type (SVLD vs nonSVLD) were analyzed with an exact Fisher test.

LuCiD scale. We analyzed LuCiD scores by grouping scale responses into their respective factors (Voss et al., 2013). We compared LuCiD scale scores using Mann-Whitney U tests between experimental groups (7:30 am cued vs 11:00 am cued; cued vs noncued) as an alternate method of quantifying lucidity, and between post-hoc groups of participants according to LD type (SVLD, nonSVLD) to test the LuCiD scale's correspondence with SVLD experience.

Individual Factors (Cued groups only). We conducted between group comparisons of SVLD and nonSVLD participants on dream recall measures and personality measures (Mann-Whitney U-Tests) and compared SVLD induction rates in participants of varying prior LD experience (Fisher exact test). Finally, we assessed relationships between nightmare distress ratings and SVLD induction rates (logistic regression), LuCiD scores (Pearson correlations) and personality measures (Pearson correlations).

Signaling and Cue incorporation (Cued groups only). We calculate SVLD duration, number of arousals during cued REM periods, and percentage of cue incorporation in SVLD and nonSVLD reports. For exploratory purposes we also discuss patterns of incorporation of the cue into dream content for different cue types.

Results

All in-text values are reported as mean and standard deviation; all figures show mean and standard error, where applicable. 40 participants reached REM sleep in their naps and were included for analyses: 7:30 am cued (n=14, 11 female, 20.86±2.71 years), 11:00 am cued (n=14,

10 female, 21.71±4.21 years), and 11:00 am noncued (n=12, 8 female, 24.00±6.32 years); groups did not differ in age ($F(2, 37)=1.618$, $p=.21$). In total there were 57 REM dream reports. 16 participants had at least one SVLD, and 24 participants did not (nonSVLD). In our sample there were cases of reported lucidity or observed signaling that did not qualify as SVLDs (see Figure 2). Thus, we further classified nonSVLDs into subcategories of dreams where the participant reported lucidity but did not complete the LR signal (Report only, n=4), instances where the LR signal was observed but the participant did not report lucidity (Signal only, n=4), and instances where neither LD report nor LR signal was obtained (nonLD, n=16).

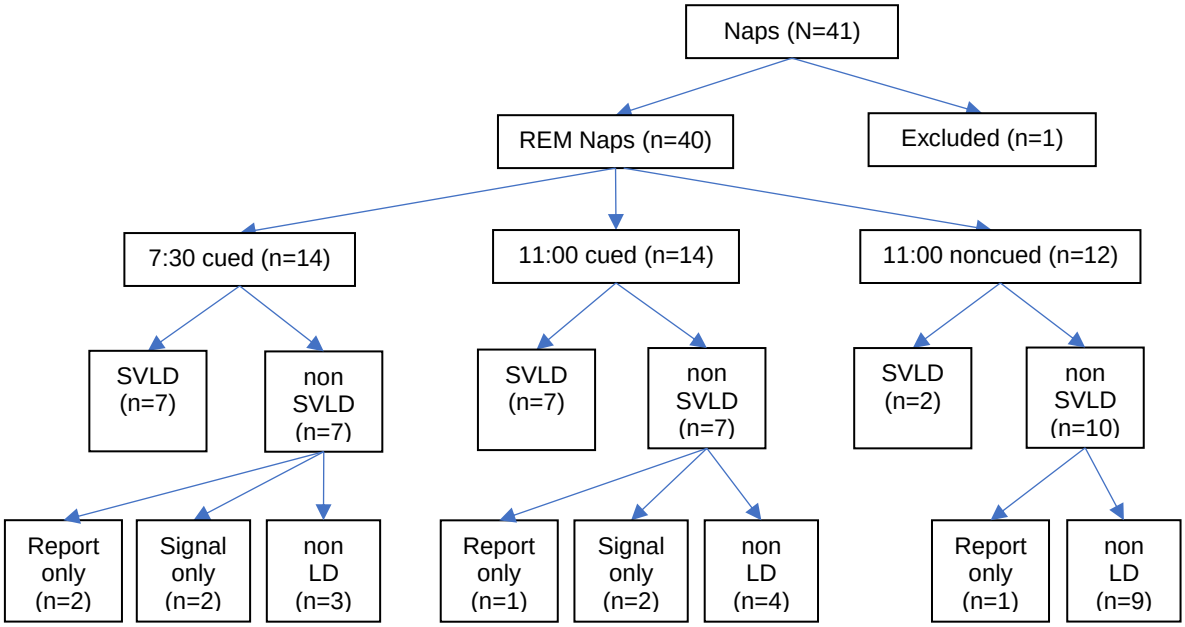

Figure 2. Counts of participants with signal-verified lucid dreams (SVLD) or without SVLD (nonSVLD). NonSVLD included instances where lucidity was reported but no LR signal was observed (Report only), where an LR signal was observed but the participant did not report lucidity (Signal only), or neither LR signal nor LD report occurred (nonLD).

Group sleep comparisons

We compared prior night sleep and laboratory nap architecture between our three groups. The laboratory sleep period was analyzed only for sleep until the awakening of interest; the first awakening was used in all but four cases where the second awakening was used, either because a participant had an SVLD on the second but not first awakening (n=2) or because a participant had a nonlucid dream on the second awakening, but no recall on the first (n=2).

Groups differed in sleep duration the night prior to coming to the laboratory ($F(2,36)=10.42$, $p<.001$) and in morning wake interval ($F(2,36)=5.51$, $p=.008$). The 7:30 am cued group had shorter sleep duration during the previous night than the 11:00 am cued ($t(25)=-3.56$, $p=.002$) and noncued groups ($t(23)=-4.07$, $p=<.001$), and shorter wake intervals than the 11:00 am cued ($t(25)=-3.31$, $p=.003$) and noncued groups ($t(23)=-2.22$, $p=.04$). Nap sleep architecture did not differ between the three groups for minutes of stage N1, N3, or REM sleep (all ps>.33), but did differ for stage N2 ($F(2,37)=3.50$, $p=.04$), due to the fact that the 11:00 am noncued group had more minutes of stage N2 sleep than the 11:00 am cued group ($t(24)=2.78$, $p=.01$).

Effect of cueing on lucidity induction

In both the 7:30 am and 11:00 am cued groups, 7 out of 14 (50%) participants had SVLDs (Fisher $p=.65$); the 7:30 am and 11:00 am cued groups did not differ on any of the LuCiD subscales (all ps>.15). We thus collapsed the cued groups for further analysis. In the 11:00 am noncued group, 2 of 12 participants had SVLDs (17%), which was fewer than for the cued groups (Fischer $p<.05$; Figure 3a).

The internal consistency for each of the LuCiD factors of Insight, Control, Negative Emotion and Positive Emotion was good (all Cronbach's alpha >.82). The factors of Thought,

Memory and Realism had lower internal consistency (alpha between .56 to .6). We removed item 5 from the Thought subscale ("While dreaming, I thought about other dream characters"), item 13 from the Memory subscale ("While dreaming, I had the feeling that I had forgotten something important"), and item 15 from the Dissociation subscale ("While dreaming, I was not myself but a completely different person"), so as to bring Cronbach's alpha above .7 for these subscales. The realism subscale had poor internal consistency (.47) and was dropped from analyses.

Comparison of LuCiD scores showed that the cued groups (N=25, 3 missing data) had higher Insight than the noncued group (N=11, 1 missing data; Z=3.31, p<.001; Figure 3b), and a trend for higher Memory (Z=1.79, p=.07); the noncued group had higher Negative Emotion (Z=-2.18, p=.03).

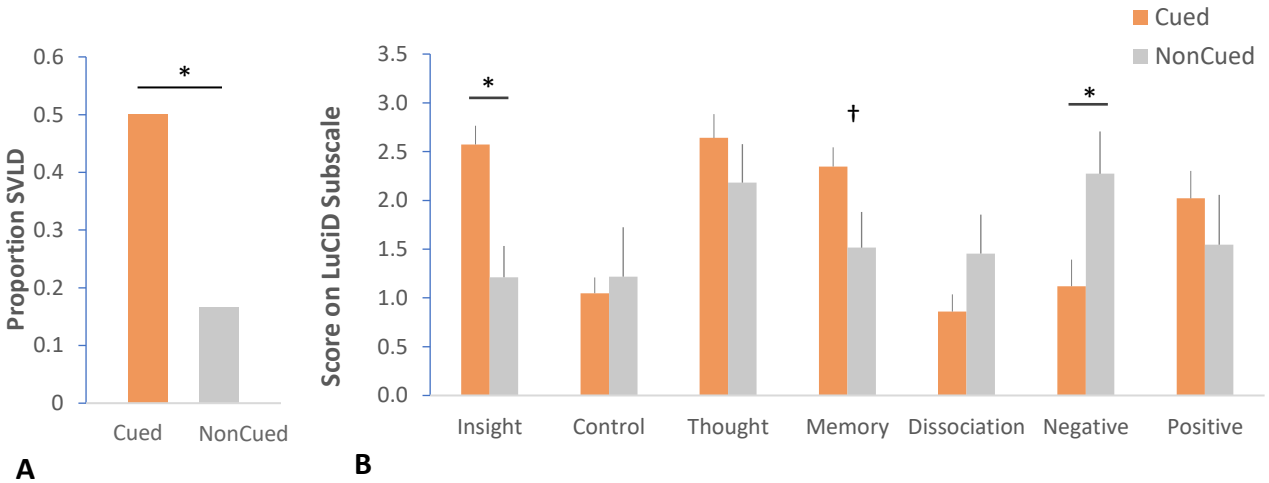

*Figure 3. Cued and noncued group comparisons of SVLD induction success and LuCiD scores. A) The 7:30 and 11:00 am cued groups combined had higher SVLD rate than the 11:00 am noncued group (50% vs 17%). B) The cued groups had higher insight, though the noncued group had higher negative emotion on the LuCiD scale. No other significant differences. †p<.1, *p<.05*

Results support that cueing effectively induced SVLDs and increased Insight as measured by the LuCiD scale.

Correspondence between LuCiD scores and SVLDs

There is debate over whether self-report questionnaires – without a direct interrogation of lucidity – are sufficient to capture whether a dream was lucid or not (Baird, Mota-Rolim, et al., 2019). The LuCiD scale is one proposed method of quantifying lucidity (Voss et al., 2014, 2013). To contribute to this discussion, we evaluated whether SVLDs from the current experiment differed in any LuCiD scale factors from nonSVLDs. We grouped our nonSVLD participants into cases of nonLD (did not report lucidity and no LR signals observed), those who reported LD but did not signal (Report only, n=4), and those who did signal without reported lucidity (Signal only, n=4). Due to low sample counts in the Report-only and the Signal only conditions, our analysis comparing LuCiD factors only compares SVLD (n=14, 2 missing data) to nonLDs (n=14, 2 missing data); we plot the Report-only and Signal-only groups in Figure 4 for descriptive purposes. We found that factors of Insight ($Z=2.71$, $p=.007$), Control ($Z=2.00$, $p<.05$), Thought ($Z=2.14$, $p=.03$) and Memory ($Z=2.66$, $p=.007$) were higher in SVLDs than nonLDs

(Figure 4), partially consistent with original reports (Voss et al., 2013).

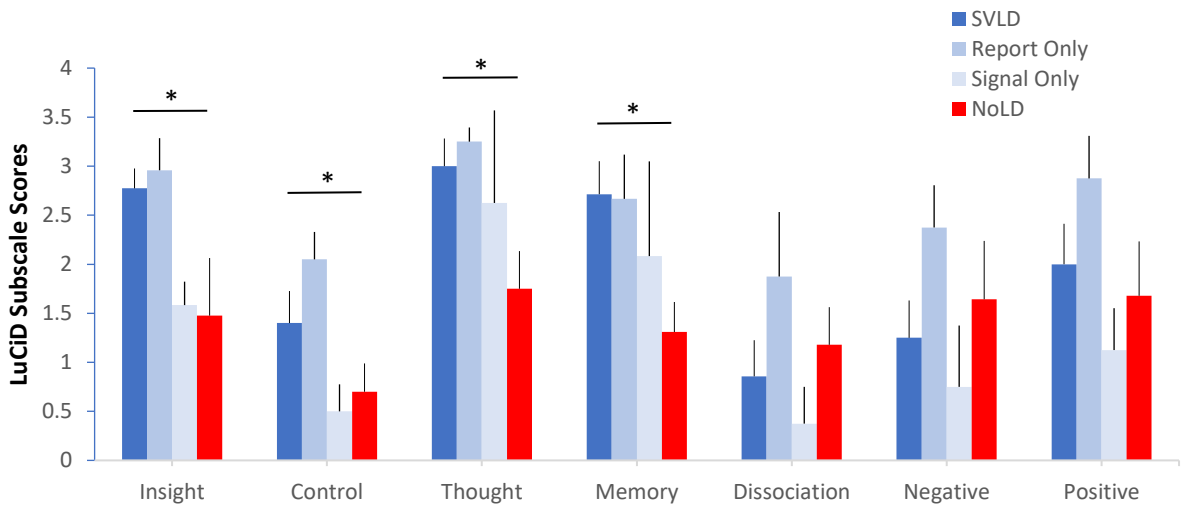

*Figure 4. Comparing LuCiD scores between SVLDs and nonLDs. SVLDs had higher ratings for insight, control, thought and memory compared to nonLDs - dreams without reported lucidity or LR signaling. Participants who reported LD but did not signal (Report only), and who did signal without reported lucidity (Signal only) are shown for descriptive purposes. *p<.05*

Factors mediating protocol efficacy (Cued groups only)

We assessed how participants' typical dream characteristics and personality may be related to LD induction success. We first explored whether LD induction success seemed to be affected by prior lucid dreaming experience. We present the distributions of reported prior lucid dreaming frequencies in the cued groups (Figure 5a); SVLD induction rates in the cued groups did not differ as a function of prior experience (Figure 5b; Fisher's p=.94). Of note, 3 SVLD participants in the cued groups had their first ever LD in the laboratory.

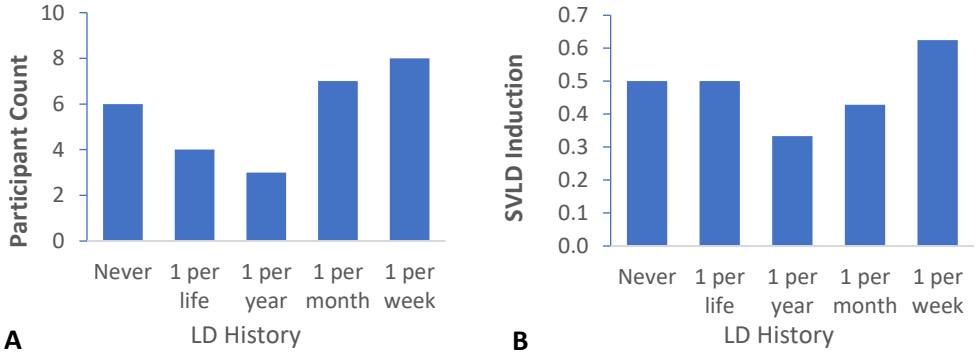

Figure 5. Induction success by lucid dreaming history. A) Distribution of lucid dreaming frequency in the cued participants and B) SVLD induction rates in the cued participants according to lucid dreaming experience.

Next, within the cued groups, we compared SVLD (n=14) to nonSVLD (n=14) participants on retrospective estimates of neutral dream, bad dream, nightmare and positive dream recall frequency, along with scaled ratings of negative or positive impacts of dreams on waking mood (1-9 scale). SVLD participants had higher nightmare distress than nonSVLD participants (5.79±3.09, 3.82±2.58, z=.34, p=.04), and a trend to higher bad dream recall per week (1.82±1.54, 0.79±0.97, z=1.75, p=.08), but neither of these were significant when controlling for multiple comparisons (corrected p<.007). No other significant differences were found (all p>.28). We also compared SVLD and nonSVLD participants on the five personality measures. All personality measures had good internal consistency with Cronbach's alphas greater than .74. No significant differences were found between SVLD and nonSVLD participants (all p>.22).

We then looked at whether nightmare distress was related to lucidity. A logistic regression found that a trending relationship where higher NM distress increased likelihood of SVLD (N=28, B=.337, p=.08). NM distress was predictive of whether or not participants reported the cues in their dreams: higher NM distress led to more cue incorporation (N=26, 2 missing

data, B=.576, p<.05). Pearson correlations conducted between NM distress and LuCiD factors (N=25, 3 missing data) revealed that higher NM distress was associated with higher Control (R=.399, p<.05), Thought (R=.499, p=.01), Memory (R=.525, p=.007), and Negative Emotion (R=.409, p=.04). Regarding personality measures (N=28), Higher NM distress was also associated with being more highly sensitive (R=.496, p=.007) and having increased dream theme diversity (R=.490, p=.008). There was a trend that higher NM distress correlated with increased mirror behaviors (R=.327, p=.09); no other relationships were found between NM distress and personality measures (all p>.17).

Signaling and Cue Incorporation

We observed between 1 to 8 LR signals from SVLD participants in response to cues (Mean = 2.93±2.37) and calculated the duration of SVLDs as the time in seconds between the first observed LR signal and awakening. SVLDs ranged in length from 25 seconds to 6 minutes and 25 seconds with an average length of 1 minute and 53 seconds (SD = 1 minute and 42.2 seconds). We presented between 1 to 14 cues total to SVLD participants (Mean = 5.71±3.73) and between 1 to 66 cues to nonSVLD participants (Mean = 15.29±18.51, *ns* p=.07). The percentage of SVLD participants who reported observing the cue in their dream (N=13, 92%) was significantly higher than the percentage of nonSVLD participants who observed the cue (N=13, 46%, Fisher's p=.02), suggesting successful incorporation of the cue into dream content may be important but not sufficient for lucidity. Cued REM periods contained between 0-4 arousals (brief awakenings from REM), with SVLD participants having on average 0.62±0.87 arousals and nonSVLD participants on average 0.71±1.27 arousals per REM period (*ns*, p=.81).

Though not a focus of the current design, we explored patterns of cue incorporation in SVLDs. External cues can either be absent from a dream report, directly incorporated into the dream (e.g., just the presence of red light), or contextualized into dream content (e.g., red light becomes burning sun). The presence of cue absence, direct incorporation or contextualization was rated by the experimenters for each of the 14 SVLD reports in the cued groups. 13 of the 14 SVLD reports contained adequate information on the quality of audio and visual cue incorporation for rating, although one participant received only one audio cue and became lucid prior to awakening, and this participant did *not* incorporate the audio cue into dream content.

Of the remaining 12 participants who received both audio and visual cues, all 12 reported the visual cue in their dream; 9 of these contextualized the visual cue into dream content, and 3 simply reported direct incorporation of the visual cue in the dream. Only 6 of 12 participants reported the audio cue in their dream, with 4 cases of direct incorporation and 2 cases of contextualization. Participants gave LR signals in response to both audio and visual cues; overall, we obtained 42 LR signals in response to cues, and 20 of these signals were in response to audio cues and 22 in response to visual cues. Refer to Table 1 for SVLD examples where the audio and visual cues were directly incorporated (Case 1), where the audio cue was incorporated and the visual cue contextualized (Case 2) and where both audio and visual cues were contextualized into dream content (Case 3). Finally, we provide examples of nonSVLD reports with cue incorporation, including a nonLD report where an LR signal was automatically provided in response to audio cue incorporation (Case 4), an LD report with visual cue

incorporation but unsuccessful signaling (Case 5), and a nonLD report with visual cue incorporation (Case 6).

Table 1. Examples of SVLD and nonSVLD reports with cue observation.

	LD Type	Dream Interview
1	SVLD Incorporation of audio and visual cues, 3 LR signals	I just had a lucid dream, just now I'm pretty sure, which was standing in a hallway and looking around…and then leaning forward and it felt that my arm was like really, off.. And then turning right into this sort of white room, which had a whiteboard and a window… *Do you remember seeing or hearing any cues?* I remember seeing the light twice I think, and hearing the beep…It didn't take a specific form, I just sort of knew it was there and just like carried on. *And did you do the eye signal movements?* I think I did yeah.
2	SVLD Incorporation of audio cues, contextualization of visual cues, 7 LR signals	I was on a stretch of beach… I remember it being really really sunny, I could almost feel the sun it was really hot…I was just kind of walking down this stretch of beach… *Did you see or hear any of the visual or audio cues?* I could tell when the red light came on because it got hot and the sun got brighter, I could see that it was getting a lot brighter. But with the audio… I heard it but it didn't link to anything I just could hear it. *And, did you do the eye movement signals each time you noticed a cue?* I did, yeah, I think I did about five signals.
3	SVLD Contextualization of both audio and visual cues, 3 LR signals	I was shopping in a supermarket, and I was just putting things in my trolley, and I could hear the beeping, and it was like I was getting loads of messages on my phone telling me what to buy in Tesco … things like, "buy some biscuits." *How many visual or audio cues did you notice?* Um, three maybe, four … [noticed the audio] through text messages…I only remembered the lights once, there's clear lights in the shop that flickered. *Did you try to do the eye movements?*

		Yeah I tried to… three [times]? Every time I heard it I tried to do it.
4	LR Signal Only Non-lucid dream with audio cue incorporation, 1 LR signal	I sat at my dinner table… I [had] a knife and fork, and I was trying to cut into this piece of meat. Then, it felt like my arm wouldn't move, and when I'd just woken up now one of my arms was a bit numb, and then, every time I could hear the noise I was trying to do the eye movements. *Did you notice any audio or visual cues?* Audio, it was just the same noise, there was no explanation for it. *Were you aware that it was a dream?* No not really… I didn't know why I was doing it. But I just felt like I had to do it. It was like I was just eating dinner at home.
5	LD Report Only LR signal attempt does not appear on EOG, visual cue incorporation	I was in the room, this room, and you'd come in and told me it hadn't worked, and you wanted to try disturbed sleep now. *And, did you know that you were dreaming?* Yeah, I knew, cause my hair was down. *While you were in the dream did you see or hear any of the cues?* It, it was like the whole light was really bright in the dream, and the dream was quite bright *And, did you try to do the eye signals in the dream?* Yeah…Uh yeah, I think I did once.
6	nonLD Non-lucid dream with visual cue incorporation	It was really weird because I didn't feel like I was asleep because I was laying there quite a while getting to sleep and so I didn't realize I was dreaming because I ended up doing the same thing in my dream as I was doing now so I feel like I was getting the [cues] but because I didn't realize I'd fallen asleep. *Were you aware that it was a dream?* No. *So, did you see or hear the cues while you were dreaming?* Yeah. Well, in my dream I still had like the mask on like I was still in the room, so [the cues were] just, like, how I see it. How I see it now *[Did you] do the eye signal movements?* No.

Discussion

SVLD induction rate

The primary motivation of the current experiment was to induce LDs in a single laboratory session. To this aim, we developed TLR—combined cognitive training paired with external stimulation immediately prior to sleep—and then re-presented cues during REM sleep. To our knowledge, the TLR protocol makes two important advances beyond previous LD induction attempts. First, we take cognitive methods of intention setting and reality checking that were previously applied over the course of days or weeks and condense them into 20-minutes immediately preceding a morning sleep period; second, we apply an explicit learning phase to associate external cues with critical self-awareness prior to sleep, and then re-present the cues from the start of subsequent REM sleep periods. To evaluate the effectiveness of cueing during REM sleep, we included a control group of participants who completed the pre-sleep training but did not have cues replayed during sleep. Reports of lucidity following the LR eye signal during sleep – SVLDs – were induced at a higher rate in cued than in noncued participants (Figure 3A; 50% vs 17%). Further, we found that cueing was associated with higher insight on the LuCiD scale, and lower negative emotion, reinforcing the notion that cueing during REM sleep had a significant impact on inducing lucidity. We did not find any difference in SVLD success or LuCiD scores between the two cued group arrival times (7:30 am, 11:00 am), and there were no differences in nap sleep architecture between the two. In principle, the 7:30 am arrival time functioned more similarly to a typical WBTB procedure, in that participants had shorter prior night's sleep and were only awake for about 2 hours (compared to 4) in the early

morning before their nap. Given the similarities in SVLD induction success, the 11:00 am arrival time may be preferable for future research as it is less taxing on the participant.

We suggest two possible mechanisms by which cue replay during sleep induces lucidity: 1) that cue observation triggers self-reflectiveness within the dream, 2) that cueing incidentally increases arousal during sleep – and wakeful awareness is transferred into the dream. That nearly all cued participants who became lucid noticed a cue in their lucid dream (92%) provides evidence that cue observation contributed to lucidity. While TLR was designed so that the cues would get incorporated and trigger lucidity in the dream, perhaps the additional reality check step ('notice whether aspects of this experience differ from normal waking experience') further enabled participants to become lucid. As illustrative, one of the nonSVLD participants in our study noticed the cues, but was in a dream of lying awake in the laboratory bedroom observing cues and thus did not do the eye signal because of the assumption that she was awake. The cue alone did not trigger lucidity despite full awareness of being in the experiment. A separate participant had a similar laboratory dream, but when she fully assessed her experience realized that her hair was up, as opposed to down as it had been when awake, and thus realized that she was dreaming. This level of critical self-awareness seems essential to provoking lucidity. On the other hand, we also find it interesting that TLR led to a conditioned response to the cue, the LR eye signal, in a few cases where lucidity was absent. This raises intriguing possibilities of experimentally manipulating non-lucid dream content with cue associations, and potentially triggering other mental states or physical actions within a dream.

The second, complementary interpretation is that cueing increased levels of arousal during sleep. Previous research shows lucid dreaming is associated with elevated levels of

autonomic activity particularly in phasic REM sleep (LaBerge et al., 1986) with higher gamma power (Voss, Holzmann, Tuin, & Hobson, 2009), higher alpha power (Ogilvie, Hunt, Tyson, Lucescu, & Jeakins, 1982; Tyson, Ogilvie, & Hunt, 1984) and more arousals during sleep (Ogilvie, Hunt, Kushniruk, & Newman, 1983). Perhaps most relevant, cueing to induce LDs is associated with higher fragmentation and arousal compared to spontaneous LDs in the laboratory (Ogilvie et al., 1983). More generally, bursts of alpha activity during late REM sleep have been proposed to enable increased processing and awareness of the external environment (Cantero & Atienza, 2000; Cantero, Atienza, & Salas, 2000). Although our SVLD participants did not have more awakenings from REM than nonSVLD participants, it's possible that other metrics of arousal, such as alpha or gamma power, could be correlated with lucidity. Future research with higher density EEG recordings could assess this possibility more precisely.

Finally, we suggest that the high level of induction may have benefitted from the fact that the cues were presented from the first indication of phasic REM sleep. The immediate cueing at REM onset may have prompted awareness at a relatively minimal stage of dream formation, as opposed to waiting to cue at a stage when a participant might be more fully immersed in the dream. Foulkes and Schmidt (1983) show that dream reports increase in length by extending dream fragments into longer narrative units; Cipolli and Poli (1992) distinguish the insertion of content into dreams on a moment-by-moment basis, from the hierarchical organization of narrative content of the dream. Thus, it might be that cues and lucidity are more likely inserted into the dream if presented early in the REM period, when the dream narrative is first developing. Future research could explore whether timing of cueing impacts LD

success, including whether cueing later in a REM period leads to less obvious incorporations of the cues or more perceptual immersion in the dream.

While these mechanisms of action remain speculative at this point, whether lucidity is trigged via cue observation within the dream and/or increased arousal during sleep, a parallel possibility is that the visual and audio cues have differing psychophysiological consequences, partially supported by our finding that visual cues were more often incorporated, although participants signaled in response to both cue types. It bears noting that a lack of reporting audio cue incorporation into a dream is not equivalent to a lack of perception, as in the paradigmatic case of the 'weak glimpse' in which participants respond to a sensory cue that is masked, even when they cannot identify it or remember what it was (as in Fazekas, Nemeth, & Overgaard, 2018). An interesting question for future research is to explore to what extent cue incorporation is implicated in SVLD success, and whether cue types across sensory modalities vary in effectiveness or mechanism of action.

The LuCiD qualities of SVLDs

Much of the past research into LD induction relies only on data from field studies, where eye-signal verification is not possible (Stumbrys et al., 2012). In these cases, often subjective report of lucidity is the only requirement for a dream to be considered lucid, barring cases where blind judges rate dream reports as lucid or non-lucid (e.g. Dyck, Kummer, König, Schredl, & Kühnel, 2018). To avoid the problem of relying on a single report item ("Were you lucid?"), Voss and colleagues (2013) developed the LuCiD scale to quantify various attributes of lucidity. In particular, Voss and colleagues (Voss et al., 2018, 2014) suggest that the subscale of *dissociation* is highly associated with lucidity; this subscale contains three items: I was a

different person completely, I observed the dream from outside, and I observed myself from the outside.

In our design, SVLD participants had higher insight, control, thought and memory than nonLD participants. LDs do not *necessarily* include control (Schädlich et al., 2017; Schredl, Rieger, & Göritz, 2018; Stumbrys, Erlacher, Johnson, & Schredl, 2014), though the element of control is important given our motivation for a research-conducive induction protocol, since many research projects are based on lucid dreamers applying control to their dream content, as are many nightmare therapies (Spoormaker & Van Den Bout, 2006; Spoormaker, Van den Bout, & Meijer, 2003). Likewise, thought and memory are important if dreamers are to remember to carry out specific tasks within the LD. We did not find the SVLD reports to be associated with higher levels of dissociation, although interestingly the few participants who reported lucidity but did *not* give the LR signal scored high on dissociation. It is possible that experiencing dissociation may precede lucidity (i.e., 'prelucid dream') in that observing one's self from the outside might enable the ability to reflect on the self and on one's current situation. While this form of 3rd person observation may persist in LDs, we suspect that the control required to give a LR signal would necessitate an immersion in rather than observation of the dreaming body. In our sample, the SVLD reports also did not contain more emotion than nonSVLD reports. It has been suggested that intense emotion is a consistent quality of LDs (Baird, Mota-Rolim, et al., 2019) although this, as we propose with dissociation, may interfere with LD control or may stimulate awakening.

Importantly, it may be that cued LDs differ psychophysiologically from spontaneous LDs. At-home lucidity often occurs as a result of sensory vividness or dissociation (e.g. out-of-body

experience) and can be an intensely emotional experience. A phenomenological study assessing shifts in insight, control, dissociation and emotion while transitioning along the spectrum of lucidity would be of interest for developing a more complete taxonomy of lucid experience.

Therapeutic implications for nightmares

We found that the participants high in nightmare distress were equally if not more responsive to the TLR protocol. Higher nightmare distress was associated with higher ratings for control, thought, memory, and negative emotion on the LuCiD scale. These findings generally fit with the profile of nightmare-prone individuals as being 'highly sensitive' (Carr & Nielsen, 2017), with dreams and waking experiences that are more pronounced in terms of cognitive processing and emotional intensity. Indeed, in our sample nightmare distress was associated with higher scores on the Highly Sensitive Person Scale. Further, our finding that nightmare distress predicted the incorporation of the cues into dreams provides further support for the increased sensory sensitivity postulated by the 'highly sensitive' trait of nightmare-prone individuals, and suggests this sensory sensitivity extends to processing during sleep.

The possibility of inducing LD in a controlled and efficient protocol has implications for the treatment of nightmares. Indeed, lucid dreaming is suggested as a first-line treatment for nightmares, such that individuals can confront and change the content of their nightmares from within a dream state towards more positive or empowering experiences (Carr & Nielsen, 2017; Holzinger, Klösch, & Saletu, 2015; Spoormaker & Van Den Bout, 2006; Spoormaker et al., 2003). In a therapeutic context, LDs are associated with an increased sense of agency and control (Holzinger et al., 2015), similar to other nightmare treatments (Ellis, 2015, 2016), and in stark contrast to the typical hopelessness and despair felt in response to nightmares (Littlewood,

Gooding, Panagioti, & Kyle, 2016; Nadorff, Pearson, & Golding, 2016). That we also found increased negative emotion in the dreams of participants high in nightmare distress is not inconsistent with therapeutic applications of LD, in that lucidity is ideally used as a tool to confront a threat in nightmares. Indeed, Sparrow and colleagues (2018) show that middle-of-the-night meditation augments both dream awareness and the presence of fear, and suggest that this would be the expected and optimal context for trauma resolution.

Finally, in our sample, we had a roughly even frequency distribution of past LD frequency (Figure 5A) and found that LD induction did not depend on prior experience: three participants had their first ever LD, in the laboratory. Given the implications of lucid dreaming beyond research and for therapeutic purposes, it is promising that, even in participants who have never had a LD, LD induction is possible. Furthermore, being able to induce LD in a sleep lab eliminates the need for participants to attempt LD training and sleep disruption tactics at home, which may further aggravate negative feelings and poor sleep if unsuccessful. One recent study found that failure to LD may be associated with lower well-being, though successful induction of a LD may boost mood (Konkoly & Burke, 2019), thus a short and effective in-laboratory protocol such as TLR would be ideal for therapy.

Limitations

Despite the effective induction of LDs, the applications of the TLR protocol remain to be tested. It is not clear what level of experimental control these SVLDs could have, although it is worth noting that subjectively our SVLDs had higher control ratings on the LuCiD scale than prior laboratory LDs (Voss et al., 2013). Thus, a major path for the research to continue would be in adding instruction to have participants attempt controlled tasks and to assess post-LD

mood and other waking impacts of SVLD success. A limitation of the current study design is that the cueing was not double-blind, so the experimenter always knew whether the participant would receive cues or not during sleep. Further, the 11:00 am noncued group had more Stage 2 Sleep than the 11:00 am cued group; it is possible that noncued participants may have shown some features of REM sleep but then returned to N2 for a period of time before entering stable REM, thus increasing their N2 length prior to awakening. Beyond this, we could not find an explanation for the difference. Another weakness of the cueing procedure was the reliance on participants' best guess of their arousal threshold during sleep, and it may be that habituation occurs in response to repeated cueing at low intensities; future research could utilize methods of discerning individual arousal thresholds *during* sleep in order to better select stimulus intensity. Finally, the lack of a second control group, in which the cues were presented during sleep but without any pre-sleep training, limits our interpretations on the precise mechanism by which TLR induces lucidity.

Conclusions

Our results suggest that a combination of condensed cognitive training and associative learning prior to external cue stimulation during REM sleep is an effective method of inducing lucid dreams. 50% of participants that received our full TLR protocol experienced a signal-verified lucid dream, a success rate that improves on other laboratory methods. That the noncued control group had lower induction success (17%) suggests that the replay during sleep of external cues, previously associated with a mental state of critical self-awareness, specifically contributed to induction success. Of special significance to future research and therapeutic applications, our data suggests this method is equally effective in participants who have little-

to-no lucid dreaming experiences and participants who have higher nightmare distress. Future work aiming to increase the length of time that induced lucidity can be maintained, and assess the level of control in the dream that can then be achieved, will be important to addressing the practical significance of this method of inducing laboratory lucid dreams.

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