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Sleep fragmentation and lucid dreaming

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ABSTRACT

Lucid dreaming—the phenomenon of experiencing waking levels of self-reflection within one's dreams—is associated with more wake-like levels of neural activation in prefrontal brain regions. In addition, alternating periods of wakefulness and sleep might increase the likelihood of experiencing a lucid dream. Here we investigate the association between sleep fragmentation and lucid dreaming, with a multi-centre study encompassing four different investigations into subjective and objective measures of sleep fragmentation, nocturnal awakenings, sleep quality and polyphasic sleep schedules. Results across these four studies provide a more nuanced picture into the purported connection between sleep fragmentation and lucid dreaming: While self-assessed numbers of awakenings, polyphasic sleep and physiologically validated wake-REM sleep transitions were associated with lucid dreaming, neither self-assessed sleep quality, nor physiologically validated numbers of awakenings were. We discuss these results, and their underlying neural mechanisms, within the general question of whether sleep fragmentation and lucid dreaming share a causal link.

1. Introduction

Lucid dreaming is a distinct phenomenon whereby waking levels of self-reflection and insight are made available to within one's dreams (Baird et al., 2019). Spontaneous lucid dreaming occurs very infrequently in the general population (Schredl & Erlacher, 2011; Saunders et al., 2016), however its frequency can be enhanced by both intentional strategies and more unintentional mechanisms. Several lines of research suggest that rapidly alternating sequences of wake and sleep periods can be associated with

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increased incidence of lucid dreaming. For example, patients with narcolepsy, who experience fragmented sleep during the night and sleep attacks during day, report significantly increased lucid dreaming frequency (Rak et al., 2015; Dodet et al., 2015). Lucid dreaming frequency has furthermore found to be associated with the self-reported number of nocturnal awakenings, and alarm clock 'snooze' function usage during morning sleep (Smith and Blagrove, 2015). In experimental studies, extended periods of wakefulness during morning hours increases the chance to dream lucidly in subsequent sleep periods (LaBerge et al., 1994; Appel et al., 2020; Erlacher & Stumbrys, 2020); a technique also known as the 'wake-back-to-bed' method (Stumbrys et al., 2012).

While lucid dreaming has been observed during NREM sleep (Stumbrys & Erlacher, 2012), it appears to occur most frequently in REM sleep (Baird et al., 2019). During normal REM sleep, brain regions that have been associated with higher cognitive processing and metacognition in particular, namely the dorsolateral prefrontal and frontopolar cortices, show decreased activation. Lucid dreaming, in contrast, is associated with functional and structural state and trait differences in the dorsolateral prefrontal and frontopolar cortices (Voss et al., 2009; Dresler et al., 2012; Filevich et al., 2015; Baird, Castelnovo, Gosseries, & Tononi, 2018).

A reasonable explanation for the association between lucid dreaming and alternating sequences of wakefulness and sleep would be the assumption that wake-associated prefrontal activation persists into subsequent sleep periods, thereby increasing the occurrence of metacognitive processing. In contrast to continuous sleep, periods of fragmented sleep would thus be expected to be associated with more lucid dreaming – potentially through the promotion a 'hybrid' state between wakefulness and REM sleep (Voss et al, 2009).

Beyond the above mentioned studies, specific investigations into the relation between sleep fragmentation and lucid dreaming have not been conducted. Generally, the association between these two phenomena requires more nuanced investigation before conclusions can be drawn. In particular, whether dream lucidity can best be understood as an artefact of deleterious or disrupted sleep, whether the inverse is true, or whether these phenomenon only incidentally correlate—so far remain unanswered.

Here, we aim to contribute to these questions by investigating the relation between sleep fragmentation and lucid dreaming through four different studies, each targeting different instances of alternating sequences of wake and sleep periods. In *Study 1,* we investigated the association between sleep fragmentation and lucid dreaming using an online survey of 202 participants recruited through internet forums and Twitter. In *Study 2,* dream lucidity was assessed through interviewing 22 volunteers about their dream experiences during and after subsisting on a radically polyphasic sleep schedule. In *Study 3* we assessed the association between self-rated sleep quality and longitudinally assessed lucid dreaming, by administrating clinical diagnostic questionnaires to 42 volunteers. In *Study 4*, we investigated the association between nocturnal arousal features and lucid dreaming, through administration of polysomnography and dream lucidity questionnaires in 30 volunteers.

Though these studies, we explored the association between sleep fragmentation and lucid dreaming using a broad-spectrum analysis of four different aspects of unconventional sleep architecture. Together, these provide a comprehensive portrait of the heterogeneities that occur within sleep architecture; and assess each one independently, in order to determine which (if any) may correlate with or account for aberrant dream metacognition.

2. Study 1: Self-assessed sleep fragmentation and awakenings

2.1. Methods

2.1.1. Participants

202 participants (age 18–63; mean = 28.91; SD = 10.96); 139 (68.81%) male, 60 (29.70%) female, 3 (1.49%) reported their gender as "other". The participants were recruited through internet forums related to lucid dreaming.

2.1.2. Materials and procedures

Dream recall frequency and lucid dreaming frequency were assessed through an online survey (Survey Monkey; https://surveymonkey.com). Beyond biographical data, the survey assessed dream recall frequency and lucid dreaming on a 9-point rating scale (*0, never; 1, less than once a year; 2, about once a year; 3, about 2 to 4 times a year; 4, about once a month; 5, 2 or 3 times a month; 6, about once a week; 7, several times a week; 8, almost every night)* based on a similar scale from Schredl and Erlacher (2004). To obtain units for dream recall and lucid dream frequency per month, the scale was re-coded using the class mean system: 0 → 0, 1 → 0.042, 2 → 0.083, 3 → 0.25,4 → 1.0, 5 → 2.5, 6 → 4.0, 7 → 18.0., 8 → 30.

The following definition of lucid dreaming was provided to ensure participants understood the phenomenon of lucid dreaming: "During lucid dreaming, one is aware of the fact that one is dreaming, while the dream is still ongoing. With this awareness it is possible to control one's dream actions or to observe passively the course of the dream" (Schredl and Erlacher, 2004).

To obtain data on continuity of sleep, participants were asked to rate their sleep on a 5-point scale ranging from: *1, highly continuous; 2, quite continuous; 3, normally continuous; 4, quite fragmented; 5, highly fragmented*. Participants were further asked to self-report: "How many times do you usually wake up at night (give your best estimate)?"

To assess the subjectively perceived link between lucid dreaming and fragmented sleep, participants were finally asked: "Do you have more lucid dreams during: *1, highly continuous; 2, quite continuous; 3, normally continuous; 4, quite fragmented; 5, highly fragmented sleep.*"

2.1.3. Statistical analysis

Two separate partial correlations between lucid dreaming frequency and sleep fragmentation and number of awakenings, respectively, were calculated, each using general dream frequency as a control variable.

Table 1
Questionnaire responses of 202 participants asked for their frequency of dream recall and lucid dreaming.

Response	Dream Recall	Lucid Dreams
never	0	21
less than once a year	1	12
about once a year	0	17
about 2 to 4 times a year	5	45
about once a month	16	47
2 or 3 times a month	23	19
about once a week	33	26
several times a week	61	12
almost every night	63	3

2.2. Results

The number of participants for the different questions differed from the overall sample ($N = 202$), due to missing data. 3 participants skipped the *average sleep continuity* question while one participant skipped the *awakenings per night* question which brought the final number for analysis down to $N = 198$. On average, respondents remembered their dreams 15.8 ± 11.4 times per month; and experienced a lucid dream almost once a week (0.31 ± 0.42) (see Table 1).

The average number of *lucid dreams per month* reported by participants was 2.7 ± 5.7. Most participants rated their sleep as *normally continuous* ($N = 78$) or *quite fragmented* ($N = 51$). The majority of participants reported having 2 or less awakenings per night (N = 147) while (N = 46) reported having between 2 and 5 awakenings, and (N = 5) reported having 6 or more awakenings. Partial correlation analyses revealed a significant association between lucid dreaming frequency and the number of awakenings ($r = 0.25$; $p < 0.001$), but not between lucid dreaming frequency and the amount of sleep fragmentation ($r = 0.05$; $p = 0.244$). However, directly asked for their impression of the association between lucid dreaming and sleep fragmentation, many participants reported having more lucid dreams during *quite fragmented* sleep (see Fig. 1).

2.3. Interim discussion

Lucid dreaming frequency was significantly associated with self-reported number of awakenings per night, as opposed to subjective degrees of fragmentation. Intraindividually, participants did however report having increased lucidity when their own sleep was determined as being fragmented. This paints a relatively mixed picture; tentatively supporting the association between fragmentation and lucidity, but doing little to narrow the focus enough to suggest an underlying physiological mechanism.

The discrepancies in these results could potentially be explained though differences in how participants self-report sleep fragmentation. For example, those whose sleep is notably fragmented (but otherwise satisfactory) could be more likely to accurately report nocturnal awakenings but under-report fragmentation; with those who are dissatisfied with their sleep more likely to exaggerate or over-report degrees of fragmentation relative to actual number of awakenings. It could likewise be the case that the types of fragmentation apt to produce the most severe deleterious sleep quality and subjective dissatisfaction (for instance multiple arousals

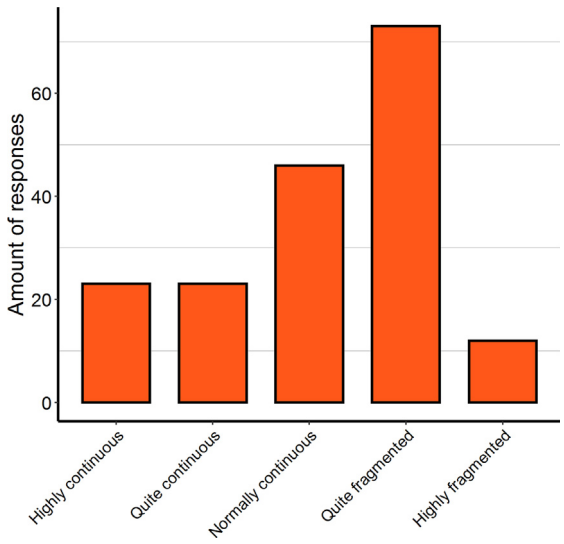

Fig. 1. Levels of sleep fragmentation that survey participants report to be most closely associated with lucid dreaming.

from light sleep) are different from the kinds of fragmentation apt to produce lucidity (arousal and re-entry into REM). It could furthermore be the case that nocturnal arousals from REM are more likely to be remembered the following morning, while multiple arousals from NREM could subjectively be perceived as a single, contiguous period; effectively resulting in under-reporting of nocturnal arousals relative to subjective and objective fragmentation.

This study provided robust indications that some connection between fragmentation and lucidity does exist; however drawing comprehensive conclusions will ultimately necessitate physiological validation, and integration of other research findings.

3. Study 2: Polyphasic sleep

3.1. Methods

3.1.1. Participants

22 volunteers were interviewed on their lucid dream frequency during monophasic vs. polyphasic sleep rhythms. Of these, 10 participants ('in-house group', 1 female, 9 male; age range 21–28, mean 23.9 ± 2.4) participated in a separate study on the cognitive and physiological effects of radically polyphasic sleep, switching to a sleep rhythm of 6 naps of 20 min each, evenly distributed across the 24-h cycle, without any extended night sleep period. We interviewed these participants within 3 months after switching back to a regular monophasic sleep rhythm. In addition, 12 participants ('external group', 1 female, 11 male; age range 18–48, mean 27.8 ± 8.8) who stated to have tried similar polyphasic sleep rhythms previously were interviewed with the same questions via email.

3.1.2. Materials and procedures

All participants of the in-house group underwent 4 weeks of preparation on their normal, monophasic sleep schedule. Sleep timing was secured by sleep diaries and actigraphy. In addition, all subjects and control subjects completed weekly questionnaires including the Altman Self-Rating Mania Scale (ASRM), the simplified Beck Depression Inventory (BDI-V2), and a questionnaire for complains of cognitive disturbance (FLei). A subsample further underwent 24 h of polysomnography (SOMNOwatch; Somnomedics, Randersacker, Germany) and blood sampling every 30 min before changing to the polyphasic sleep schedule. During this 24 h monitoring, participants further underwent tests of declarative and procedural memory, fluid reasoning, and psychomotor vigilance. The polyphasic schedule was planned to last until a second 24 h monitoring after 8 weeks. In case of premature termination, a custom-made questionnaire asked for different reasons for terminating the polyphasic sleep schedule.

Participants of the external group were sampled from independent attempts to switch on a polyphasic sleep schedule, and thus did not share any systematic testing or procedures beyond the lucid dreaming interviews.

All participants were interviewed after termination of the polyphasic sleep rhythm, and were interviewed for their dream experiences during the period of polyphasic sleep and during the subsequent period with a regular monophasic sleep rhythm.

Both frequency of dreaming and frequency of lucid dreaming was assessed with a 6-point-rating scale for the time period with a polyphasic sleep rhythm (0: never, 1: monthly, 2: weekly, 3: after one nap/24 h, 4: after several naps/24 h, 5: after each nap/24 h) and with an 5-point-rating scale during for the time period with a regular monophasic sleep rhythm (0: never, 1: monthly, 2: weekly, 3: daily, 4: several dreams a day). The same definition of lucid dreaming as in study 1 was given. To obtain units for dream recall and lucid dream frequency per day, similarly to study 1 (and Schredl and Erlacher, 2004) the scale was re-coded as follows: 0 → 0, 1 → 0.03, 2 → 0.25, 3 → 1.0, 4 → 3.0, 5 → 6.0 for polyphasic sleep; and 0 → 0, 1 → 0.03, 2 → 0.25, 3 → 1.0, 4 → 3.0 for monophasic sleep.

In addition, participants were asked if their sleep quality (difficulties in falling asleep and difficulties to sleep through) was different during polyphasic compared to monophasic sleep (possible answers 1. much better, 2, better, 3. comparable, 4. worse, 5. much worse). The study was approved by the ethics committee of the Medical Faculty of the Ludwig Maximilian University, Munich.

3.1.3. Statistical analysis

Two participants of the external group had to be excluded due to inconsistent answers (more lucid dreams than dreams overall). We compared the self-reported lucid dreaming frequencies ofthe remaining 20 participants during polyphasic vs. monophasic sleep using a Wilcoxon signed-rank test. As a control, we performed another Wilcoxon signed-rank test for relative lucid dream frequencies, i.e. lucid dream frequency divided by general dream frequency. As another control, we correlated the individual change in lucid dreaming frequency with the reported change in sleep quality.

3.2. Results

Participants of the in-house group kept the polyphasic sleep rhythm for a duration of 3–44 days (mean 16.7 ± 12.9) before switching back to a normal sleep rhythm. Participants of the external group spent 3–220 days (mean 41.9 ± 68.3) on a polyphasic sleep rhythm before switching back to a normal sleep rhythm.

Participants reported 2.64 ± 1.90 dreams per day during and 0.81 ± 1.01 dreams per day after cessation of the polypohasic sleep rhythm. They further reported 0.50 ± 0.92 lucid dreams per day during and 0.05 ± 0.09 lucid dreams per day after cessation of the polypohasic sleep rhythm (see Fig. 2).

Paired t-tests indicated that these differences in both absolute ($t_{19} = 2.31 p = 0.016$) and relative ($t_{19} = 2.3$, $p = 0.016$) lucid dreaming frequency between polyphasic and monophasic sleep rhythms were significant. In contrast, a Pearson correlation did not

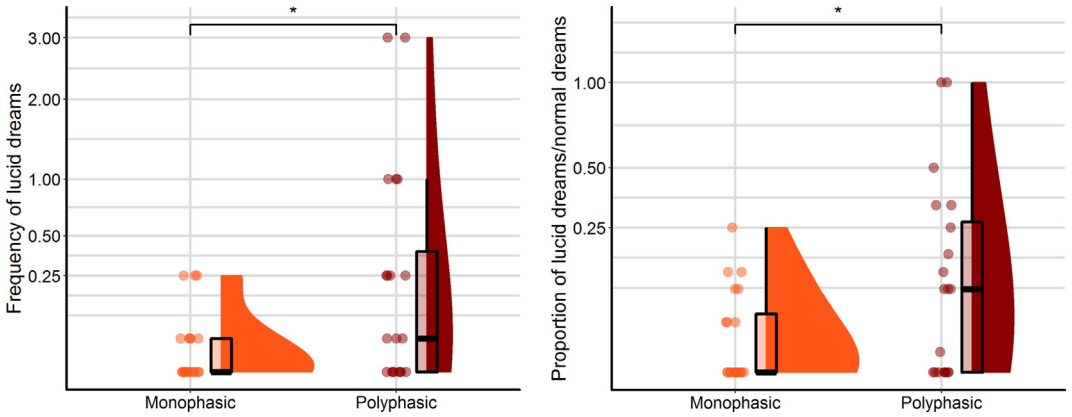

Fig. 2. Self-assessed lucid dreaming frequency is increased during a polyphasic sleep schedule compared to monophasic sleep. Left: absolute number of lucid dreams per day. Right: number of lucid dreams per day relative to general dream recall frequency.

find a significant association between the change in lucid dreaming frequency and the change in sleep quality during vs. after polyphasic sleep ($r = -0.14$, $p = 0.58$). This did not change when the change in lucid dreaming frequency was normalized by general dream frequency ($r = 0.06$, $p = 0.82$).

3.3. Interim discussion

Compared to a single period of extended sleep as experienced in regular monophasic sleep schedules, participants on radically polyphasic sleep schedules with alternating periods of sleep and wakefulness across the 24-hour cycle appear to experience an increased number of lucid dreams. This difference seems to be robust, as it can be demonstrated for both absolute numbers of lucid dreams experienced per day and the proportion of lucid dreams in relation to general dream recall frequency. Compared to rather brief periods of wakefulness that might characterize fragmented sleep during normal sleep patterns, radically polyphasic sleep allows for extended periods of wakefulness preceding an increased number of sleep episodes, and likely for REM periods following wakefulness more closely than in extended monophasic sleep episodes. Both factors might increase the probability of a still activated prefrontal cortex meeting a REM episode, and thereby increasing the chance of experiencing a lucid dream.

4. Study 3: Sleep quality

4.1. Methods

4.1.1. Participants

42 healthy volunteers (29 females, 13 males; age range 18–34, mean 22.8 ± 4.1) were included. The participants were recruited via the participant recruitment system of the University of Amsterdam and at the Radboud University Nijmegen as part of an independent larger project (not further discussed here). Only volunteers who remembered their dreams at least three times a week and who had personal experience with LD were included. Exclusion criteria were: current or history of sleep problems, psychiatric or neurological disorders such as anxiety or depression, night shift work, excessive use of alcohol, cigarettes or other recreational or psychoactive drugs. One participant reported experiencing sleep paralysis during multiple nights and was excluded from the dataset. All participants gave written consent after the procedures had been fully explained and were paid for their participation. The research was approved by the ethics committee of the University of Amsterdam and the CMO Regio Arnhem-Nijmegen.

4.1.2. Materials and procedures

Pittsburgh Sleep Quality index (PSQI; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). The 19 questions of the PSQI are related to the sleep habits of the participant during the past month (e.g. When have you usually gone to bed at night? How often during the past month have you had trouble sleeping?). These 19 questions are combined to form seven different component scores: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication and daytime dysfunction. Each component score has a range of 0–3 points, in which a score of '0' indicates no difficulty and a score of '3' indicates severe difficulty. A global score is obtained by adding all seven component scores, leading to a range of 0–21 points, with higher global PSQI scores indicating a worse sleep quality.

Dream Lucidity Questionnaire (DLQ, Stumbrys et al., 2013). The DLQ measures different aspects of lucidity within dreams. It consists of twelve items assessing awareness as the core aspect of lucid dreaming (awareness that dream characters/objects are not real, awareness of dreaming, awareness that the physical body is asleep), and further different types of control (changing dream scenes/characters/events, breaking the physical laws, deliberately choosing an action), and remembrance (of intentions and of waking life). Each item has to be scored on a 5-point scale (0—not at all, 1—just a little, 2—moderately, 3—pretty much, 4—very

much). The total DLQ score was derived as mean of all original items except for item 7 and 12. This was because these questions loaded poorly (< 0.4) in the original factor analysis that produced the DLQ; relating predominantly to recall of "waking facts, episodes or intentions" and not lucidity per se (Stumbrys et al, 2013). As such, all DLQ scores were out of a maximum of 40 points.

Volunteers who were interested in participating in the study were invited to fill out a preliminary survey during the first week of the study. This survey consisted of the demographics questionnaire and the dream frequency/general attitude towards dreams/level of control questionnaire. Based on these questionnaires volunteers were included or excluded in the study. Included participants completed the PSQI once at the beginning of the study, and daily questionnaires on dream lucidity (DLQ), sleep and mood every day for six weeks.

All participants gave written consent after the procedures had been fully explained and were paid for their participation. During the experiment, participants were asked not to read any additional information about lucid dreaming outside what this study provided to them, since this could potentially bias the results. The research was approved by the ethics committee of the University of Amsterdam.

4.1.3. Statistical analysis

The data reported here focuses on the DLQ and PSQI questionnaires. For this study, we focused in particular on question 5b: During the past month, how often have you had trouble sleeping because you wake up in the middle of the night or early morning (possible answers: 0: Not during the past month, 1: Less than once a week, 2: Once or twice a week, 3: Three or more times a week). Pearson correlations were computed to provide insight into the relation between a longitudinal measure of lucid dreaming (mean of the 42 DLQ questionnaires) and PSQI question 5b and the global PSQI score, respectively.

4.2. Results

The mean global PSQI score before the 6-weeks period was 4.48 ± 1.72, indicating some variability in the sample, but was mostly still in the healthy (i.e. not clinically sleep disturbed) range. The mean score for PSQI question 5b was 1.38 ± 0.90, again indicating variability in the sample but no strong complaints about nocturnal awakenings. The mean DLQ score across all subjects and nights was 5.46 ± 6.63. We found no significant correlation between nocturnal awakenings as measured by PSQI question 5b and lucid dreaming as measured by the DLQ score ($r = -0.02$, $p = 0.88$) during the 6-weeks period. We further found no significant correlation between global PSQI scores and the average DLQ score ($r = 0.1$, $p = 0.53$).

4.3. Interim discussion

No correlations were found between nocturnal awakenings or overall sleep quality and dream lucidity. Since the PSQI is designed as a diagnostic tool for clinical purposes, it can therefore be concluded that if a connection between sleep disturbance and lucidity does exist, this particular tool is not apt to measure it; or that such disturbance is reasonably unlikely to be deleterious as per clinical definitions.

5. Study 4: EEG arousals

5.1. Methods

5.1.1. Participants

30 participants (7 males, 23 females; age range 18–27; mean 21.1 ± 2.13) were recruited from the student population of Radboud University in Nijmegen, Netherlands. Inclusion criteria included 'dream recall frequency' of ≥ 3 dreams per week, consistent sleep schedule, and infrequent alcohol intake (*Socially on Weekends* included, *One drink with a meal* excluded). Exclusion criteria were the presence of health or sleep related issues, prescription of psychopharmacological medication, drug use exceeding recreational and legal standards, and ongoing shift work.

5.1.2. Materials and procedures

Lucidity and Consciousness in Dreams Scale (LuCiD; Voss, Schermelleh-Engel, Windt, Frenzel & Hobson, 2013). The LuCiD measures key aspects of dream lucidity in detail and consists of 28 statements (e.g. While dreaming, I was aware of the fact that the things I was experiencing in the dream were not real; While dreaming, I thought about my own actions). Participants had to rate to what extent they agreed or disagreed with the statement on a 5-point scale from strongly disagree (0 points) to strongly agree (5 points), with unlabeled numeric values of 1–4 between these points.

For each participant, a night of sleep was recorded via ambulant 16 channel polysomnography (Somnoscreen plus, Somnomedics) using the 10/20 system, with a ground location on the forehead and the reference location on Cz, 2 EOG channels on the outer canthi, 2 EMG channels on the chin area referenced to a third channel, 2 ECG channels for electrocardiograph activity attached to the right collarbone area and under the contralateral ribs. Polysomnography was applied in the evening at Donders Institute, participants then went home and brought the Somnoscreen back the following morning. The raw EEG data was pre-processed through DOMINO (https://www.dominodatalab.com), with a software-based hypnogram produced. Pre-processed .EDF files were subsequently imported into SpiSOP (https://www.spisop.org) for manual sleep scoring and artefact rejection. Sleep scoring was performed for subsequent 30 s epochs according to standard scoring system (Iber, Ancoli-Israel, Chesson, & Quan, 2017) to obtain sleep

macrostructural variables. Two independent scorers performed a first scoring and a third scorer was used in cases of disagreement on sleep scoring. Arousals were analysed automatically by DOMINO and then manually quantified. Transitions (awakenings) between sleep and wake were counted manually.

Based on the hypothesis that dream lucidity achieved by the wake-back-to-bed strategy (LaBerge et al., 1994; Appel et al., 2020; Erlacher & Stumbrys, 2020) could be explained by waking levels of prefrontal activity persisting into subsequent REM sleep (Dresler et al., 2012), we analysed the number of wake-REM sequences (WREM); defined as the number of times a participant successfully entered or re-entered into REM from an aroused state within 5 min. Specifically, an aroused state was defined by either a continuous wake period that spanned at least two epochs, or a single wake epoch or arousal that resulted in a transition through sleep stages 1 and 2 before returning to REM. When these conditions were met, a 'Wake REM sequence' was recorded. Where discrepancy between two independent raters' scoring of ambiguous arousal/wakefulness events resulted in different numbers of WREM sequences being counted for a single sleep recording, the average of these two was taken.

In addition, we assessed the Number of Awakenings (NOA) and Total Wake Time (TWT), independent of REM sleep transitions. All three measures were assessed manually in addition to automatic analysis using an R script (https://www.r-project.org). We initially assessed only the two last hours before final awakening, given that REM sleep incidence is highest in the morning hours and the assumption that dream recall is most robust for dreams close to awakening and reporting, and the preponderance towards lucid dreams occurring during the hours that precede awakening. In an exploratory analysis, we varied this time window and the timing of the wake-REM transitions.

In the morning after polysomnography, subjects had to fill out the LuCiD immediately after awakening. The research was approved by the responsible ethics committee CMO Regio Arnhem-Nijmegen.

5.1.3. Statistical analysis

Pearson's correlation coefficients were computed to analyze the relation between the main lucidity factor *Insight* and the three sleep parameters. Additional exploratory correlational analyses were performed for the remaining lucidity factors, and for different timings of the sleep parameters.

5.2. Results

Participants experienced on average 1.17 ± 1.07 (range: 0–5) wake-REM sequences in the last two hours of the night. A significant correlation was found between the number of wake-REM sequences and the lucidity factor *Insight* ($r = 0.357 p = 0.026$) as seen in Fig. 3. There was no correlation found between *Insight* and *Number of Awakenings* ($r = 0.011$, $p = 0.478$) or *Total Awake Time* ($r = -0.081$, $p = 0.336$).

Under exploratory analysis, wake-REM sequences did not significantly correlate with any other LuCiD scales (*Realism*: $r = -0.078$, $p = 0.34$; *Control*: $r = 0.258$, $p = 0.084$; *Memory*: $r = -0.077$, $p = 0.343$; *Thought*: $r = -0.219$, $p = 0.123$) however *Control* did come close to significance threshold. LuCiD scales did not correlate with either *Number of Awakenings* or *Total Awake Time*, with the exception of the subscale *Realism*, which anti-correlated *Number of Awakenings* ($r = -0.341$, $p = 0.033$).

For further exploratory analysis, we varied the temporal parameters (last 2 h of sleep, 5 min wake-REM sequences) to determine whether these were adequate, and justifiable for re-employment in future analyses. Since both of these variables were chosen somewhat arbitrarily, it was pertinent to investigate whether lucidity from previous REM epochs (beyond two hours) could have been

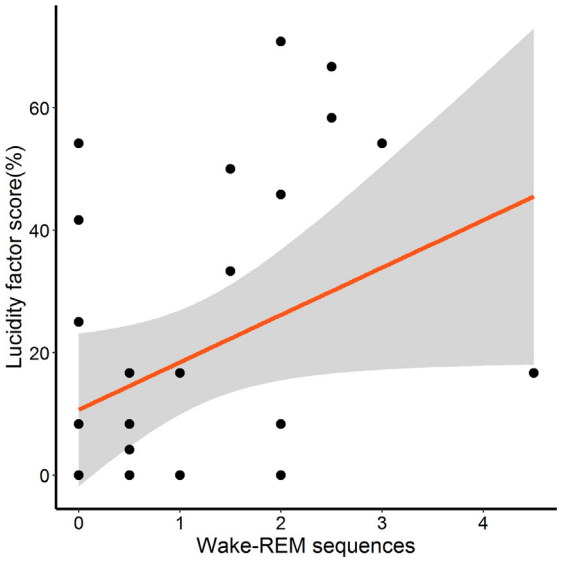

Fig. 3. Regression analysis of Lucidity factor *Insight* and wake-REM sequences ($r = 0.357$ $p = 0.026$, $n = 30$).

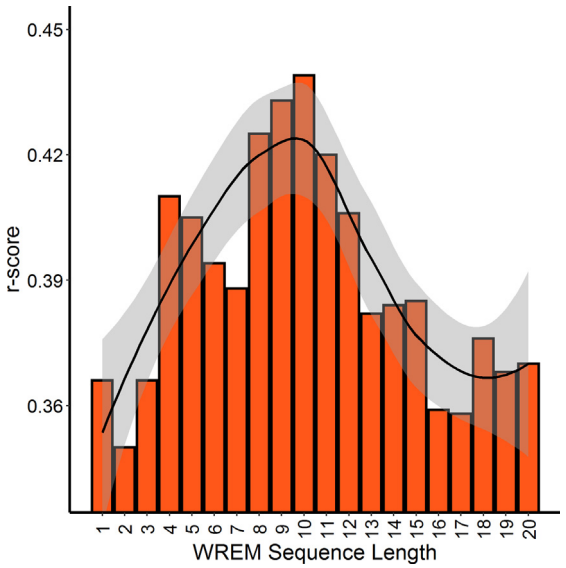

Fig. 4. R values of the lucidity factor *Insight* using varied wake-REM sequence lengths between 1 and 20 min, over the last 4 h of sleep (n = 30).

driving some of the questionnaire answers; and indeed whether the 5-minute wake-REM sequence was optimal for capturing the observable phenomena in question, at its maximal statistical power. The analysis of the association between wake-REM transitions and dream lucidity came out much stronger when applied to the last 4 h of sleep (including 3.57 ± 2.29 wake-REM sequences, range 0–8), and also appeared to maximise at this threshold. The chosen length of the wake-REM sequence did not change the effects substantially when varied between 1 and 20 min, but appeared to maximise between 5 and 10 min, diminishing above and below this window. The highest r value was at 10 min (r = 0.439) while the lowest was at 2 min (r = 0.35), as seen in Fig. 4.

5.3. Interim discussion

While no correlation was found between self-reported lucidity and either *Number of Awakenings* or *Total Wake Time*, the correlation between our novel variable w*ake-REM sequence* did indicate a potential connection between dream lucidity, sleep architecture and underlying physiological processes. Moreover, this result provided a clear and concise avenue by which to further investigate and quantify WBTB-based lucidity induction. While this variable provided preliminarily promising results, fully understanding its role within dream lucidity will require further analysis beyond that carried out though this investigation.

The somewhat arbitrarily chosen parameters of 5 min for time taken between arousal and REM re-entry appeared, under exploratory analysis, to be reasonably well chosen. However, in retrospect, analysis of the final 4 h of sleep was more desirable (particularly with wake-REM sequences set at 10 min) as the observed effects were considerably stronger at these points. Even though lucid dreams tend to occur more often in later REM periods (LaBerge et al., 1986), in principle they can be remembered from any nocturnal REM epoch. It thus seems plausible that taking a longer view into the hours preceding waking simply captures more overlap between the empirical and subjective data. An ideal timing of wake-REM to support lucid dreaming remains to be established though.

Results of the last study tentatively support a link between sleep fragmentation and dream lucidity, at least for the case of wake-REM sequences. Future analysis might explicitly investigate neurophysiological correlates of these sequences; attempting to expand this investigation to determine where and how given brain structures retain waking levels of activity as a deeper causal substrate for maintenance of metacognition during dream re-entry.

6. General discussion

The four studies presented here paint a rather nuanced picture of the hypothesized connection between sleep fragmentation and lucid dreaming: self-assessed numbers of awakenings, polyphasic sleep and physiologically validated wake-REM sleep transitions were associated with lucid dreaming; in contrast self-assessed sleep quality and physiologically validated numbers of awakenings were not.

At the neurophysiological level, it is tempting to speculate that sleep interruptions causally increase the likelihood of elevated activity in the prefrontal cortex persisting into REM sleep, and that such activity can explain the neurobiological mechanisms behind the results observed. Sleep onset REM episodes also occur in healthy subjects, particularly after periods of sleep interruption during the night (Fukuda et al., 1987; Miyasita et al., 1989; for a review see Takeuchi et al., 2002) and during daytime naps (Bishop et al., 1996; Singh et al., 2006). A common feature of sleep fragmentation seen in both pathological conditions such as narcolepsy and intentional sleep disruptions that promote lucid dreaming are thus REM periods rapidly following wake periods characterized by

more activated metacognition-related prefrontal brain regions. In such a physiological (or 'bottom up') model—activity in the prefrontal cortex would normally remain active during the return to REM, through a process of inertia (Hobson and McCarley, 1977) with higher numbers of wake-REM sequences comparatively maximising the likelihood of this happening. This would appear to be supported by research into narcolepsy, a pathological condition involving hypothalamic abnormalities in Orexin projecting neurons, which predicts dream lucidity significantly (Rak et al., 2015). However, the direction of causality becomes complicated with this explanation, and as such, this conclusion would be premature to draw. Narcolepsy is associated with richer than average dream content (Schredl, 1998; Fosse, 2000; Cipolli et al., 2008) indicating some degree of *heightened* cognitive function associated with its pathological presentation. Therefore, it can only be said that sleep disruptions may increase the chance of wake-REM sequences; with the predilection for vivid dream content (in these circumstances) requiring an alternate explanation. It would therefore be interesting to see whether lucidity correlates specifically with wake-REM sequences in sleep of Narcolepsy patients too.

A psychological (or 'top down') interpretation would also be consistent with the observations of this study. This would suggest that spontaneous metacognitive activity produces lucidity in reported cases, with such activity also coming at a cost—sleep is more likely to be disrupted, through 'failed' lucidity attempts that activate and arouse the entire brain as an unintended consequence. This would be difficult to refute directly, since other studies involving alarm snooze button use (Smith and Blagrove, 2015) and late night gaming (Gackenbach, 2009) as mechanisms to induce dream lucidity could not rule out lucidity as the primary goal of the behaviour; with voluntary 'disruption of sleep' serving as a crude means of achieving this outcome. To determine the value of this explanation, it would be interesting to investigate whether failed lucidity attempts (that instead result in full arousal) are particularly likely to result in a rapid return to REM. However, this could only be determined through empirical methods, which would in turn require a deeper understanding of the underlying neurophysiology and electrophysiology that underpin these phenomena, in order to capture these attempts outside of subjective reports.

These competing explanations could potentially be balanced by a third option; one that involves both psychological and physiological processes. Several waking studies have suggested that diminished cognitive performance through sleep fragmentation and deprivation can result in functional 'independence' of certain key hubs of the default mode network, including the precuneus (Chee and Chuah, 2007) which also share crucial importance with lucid dreaming (Dresler et al, 2012; Dresler et al, 2015), virtual representation (Cavanna and Trimble, 2006; Utevsky et al., 2014) and mind wandering (Mason et al, 2007; Christoff et al, 2009; Schooler et al, 2011). Together, this indicates that it is plausible for high level cognitive content to emerge once the physiological processes that constrain their manifestation become voluntarily or involuntarily disrupted. Such an interpretation coheres with theoretical models of brain function that view the mind in terms of primary and secondary processes (Dresler et al., 2009; Hobson, 2009; Hobson and Voss, 2010; Hobson and Voss, 2011), and indeed, many models of psychosis (Limosani et al., 2011; Dresler et al., 2015; Scarone et al., 2007) which also suggest that sleep-based stressors can cause certain types of brain function to experience heightened activation, through brain function as a global phenomenon becoming negatively impacted. As such, one cannot conclusively determine how the wake-REM sequence manifests or functions, at either the physiological or psychological level; but future investigations would be well placed to explicitly examine the neurophysiological correlates of such phenomena, and consider these theoretical discussion points, to help answer this question.

7. Concluding remarks

Our studies represent a diverse assemblage of the variety of ways that sleep fragmentation might contribute towards incidences of metacognition during sleep. The concluding picture that emerges from these studies is that *deleterious sleep* does not seem to have a substantive effect on dream lucidity. For subjective and objective sleep fragmentation the picture is mixed, with dream lucidity being associated with self-reported number of awakenings per night and polyphasic sleep, but not subjective degrees of fragmentation or dissatisfactory sleep; even though participants had the subjective impression that lucid dreaming occured most often in sleep that was quite fragmented. What does appear plausible is that rapid re-entry into REM sleep from a waking or aroused state does increase the chance of experiencing a lucid dream—and that fragmented or polyphasic sleep might indeed potentiate such occurrences. Our preliminarily hypothesis that rapid re-entry into REM sleep from a waking state supports increased incidences of dream lucidity can therefore be supported, laying some deeper context to the neurophysiological processes potentially responsible for the efficacy of the wake-back-to-bed strategy of lucid dream induction. Our findings thus indicate that the presence of a relatively specific sleep architectural phenomenon might be the causal instigator of dream lucidity, which may manifest as a consequence poor sleep, but does not require it. Given recent concerns about potential detrimental effects of lucid dreaming on sleep quality and/or sleep function (Vallat & Ruby, 2019; Soffer-Dudek, 2020), this distinction is an important one—lending further support to the findings of a recent study (Schadow et al., 2018) which showed no correlation between poor sleep and lucidity once nightmare content was controlled for.

Future investigations into lucid dreaming would do well to consider the wake-REM sequences and their role in potentiating the neurophysiological mechanisms that might underlie dream metacognition; and should consider this as a distinct variable from fragmentation per se. The efficacy of the wake-back-to-bed technique, together with unusual sleep scheduling (including morning REM naps) might be reconciled within the context of sleep fragmentation; with a meaningful distinction now available between deleterious and potentially more benign categories of sleep fragmentation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.concog.2020.102988.

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