COGNITION DURING SLEEP: HYPERASSOCIATIVITY, ASSOCIATIVITY AND NEW CONNECTIONS

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COGNITION DURING SLEEP: HYPERASSOCIATIVITY, ASSOCIATIVITY AND NEW CONNECTIONS

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EDITORIAL
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Editorial: Cognition During Sleep: Hyperassociativity, Associativity and New Connections

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Keywords: sleep, cognition, consciousness, hyperassociativity, memory, consolidation

Editorial on the Research Topic

Cognition During Sleep: Hyperassociativity, Associativity and New Connections

The purpose of this collection was to collate evidence and emerging ideas from the neurosciences, cognitive sciences, and consciousness studies to understand the nature of cognition in sleep. In particular, within the literature on dreaming, cognitive processes of "hyperassociativity," or "loose connections," have been suggested to be a key feature of Rapid Eye Movement (REM) sleep and dreaming. Hyperassociativity has been ill-defined, though it seems to comprise diffuse, surprising or weakly-linked memories or memory fragments, which are activated either sequentially or in parallel during a dream. Recent scholars have proposed that hyperassociativity may create the environment in which novel insights, new solutions and creativity can flourish and may therefore underpin some of the cognitive benefits of REM sleep. REM dreaming, in particular, may have evolved to spot non-obvious, remote associations which, coalesce to visualize probabilistic patterns in past events.

The papers within this Research Topic explored and considered cognition during sleep from several angles.

Nordin and Bjälkebring(a) sparked a debate within the issue concerning the nature of cognition within REM sleep, as contextualized as the supernatural agent (a facet of self) in dreams, with Sears responding with a critical dismissal of the underpinning theory, and the original authors [Nordin and Bjälkebring(b)] responding again. The debate concerned the nature of counterintuitiveness in dream imagery, what such cognitive structures could represent and how it could be measured. Whilst the original authors [Nordin and Bjälkebring(a)] made use of a coding scheme devised by Barrett (2008) for the first time, Sears raised some methodological and conceptual criticisms of this. The debate highlighted the need for further clarity surrounding measures of dreaming cognition, as well as the range of approaches to studying it within dream science.

Barcaro et al. illustrated the complexity of cognition underlying consciousness in terms of dream formation and possible purpose, with three dreams. They considered the parallel processes involved with hyperassociativity, i.e., the simultaneous activation and combination of several memory sources, along with the activation—or perhaps even suspension of—present concerns (as such concerns seem to motivate the dreamer toward reducing the negative emotionality associated with those experiences). However, such complex parallel processes lead to an apparently serial presentation of dream images within the dream scenario. The authors must be congratulated for synthesizing theories of consciousness and cognition as a means of accounting for dream

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formation. We suggest that hyperassociativity allows for the presentation of these numerous memory sources in dreams, or sleeping cognition, potentially reconciling these models.

Hołda et al. explored the effect of a 90-min nap, relative to comparable wakefulness, of problem solving using a real-world task featuring the presentation of a crime story via an interactive computer task. Sleep architecture revealed that all participants experienced REM as well as all non-REM stages. Contrary to expectations, no effect of sleep on problem solving was found. Neither quality nor creativity of the solutions generated by the participants was higher in the nap group than in the waking group, though naps only lasted around an hour on average.

Similarly Solomonova et al. did not identify global benefits of sleep on cognitive outcomes (in this case a procedural memory consolidation task), but rather, a more nuanced one. They compared meditation practitioners with non-meditating controls on both the memory outcomes and sleep architecture. Whilst architecture was comparable overall, task performance correlated with spindle activity in the meditation group, but with REM in the control group. The authors speculate that meditation may alter sleep architecture in response to learning and memory, which indicates possible learned mechanisms for reorganizing neural architecture. The possibly more dynamic, rather than fixed, nature of cognition during sleep is therefore suggested.

Fogel et al. also investigated relationships between sleep and learning by exploring dream content in response to recent prior learning, as mediated by inter-individual reasoning (for early dreams) and verbal abilities (for later dreams). Dreams reported from early in the night reflected the extent of learning within the reasoning task. In that way the findings demonstrated possible links between dream production and manifestation, and specific cognitive styles during wake.

Vallat et al. explored group trait differences in dream recall. They demonstrated that medial prefrontal cortex white matter density was greater in high dream recallers compared to low dream recallers. Whether the anatomical differences result from learning or are congenital, we cannot say, however accumulated evidence indicates the importance of the medial prefrontal cortex in dream recall—or perhaps dream production. The more evidence we can accumulate concerning the neural substrates underlying dreaming, the better we may be able to make inferences about the large-scale function of dreaming, particularly in relation to memory- or emotion-processing.

Continuing this exploration of traits, Blagrove et al. considered both state and trait empathy as related to dream sharing. Trait empathy was found to be significantly associated with the frequency of listening to the dreams of others, frequency of telling one's own dreams to others, and attitude toward dreams. In a second study, dream sharing increased state empathy, leading the authors to suggest that these relationships between dreaming and sharing of experiences may afford us the opportunity to use dreams to facilitate social bonding. In this way, the sleep mentation may be functional. It may also be open to change or distortion, reiterating Solomonova et al.'s sentiments above that sleeping cognition may not be fixed.

Kahn explored continuity in terms of the self and noted that the cognitive reactions to activity during sleep, in the context of dream activity, was somewhat discontinuous with waking life but continuous with the dream activity, such that dream content was bizarre by waking standards, but it was largely accepted during the dream. Kahn gives examples of dream content whereby there are changes in situations, or hyperassociativity of places and times, but that these are accepted by the dream-self. Thus, hyperassociative cognition during sleep seems to be a "normal" part of activity at that time. This acceptance may also hint at the function (or functions) of hyperassociativity."

Rozen and Soffer-Dudek investigated the physiological and psychological correlates of a specific yet common dream event: that of teeth falling out, in an attempt to explore the continuity hypothesis. Teeth dreams were associated with specific measures of current dental distress and irritation, whereas other (non-teeth dreams) were not associated with such dental distress. Whilst this does not support the continuity hypothesis in terms of memories, or recent events, being reactivated during sleep and consequently manifesting in dreams, it does support the continuity of perceptions and concerns, whilst going against the more symbolic notions that teeth dreams may be a representation of something non-physiological. This clear and helpful illustration of a specific dream theme has helped to elucidate some of the more universal cognitive mechanisms underlying dream production.

Taken together, this collection has explored the cognitive correlates of sleep and dreaming, articulating the apparently more universal nature of hyperassociativity for the first time. We propose that identifying cognitive features of sleep over the course of the night may provide insights as to sleep's function, whilst recognizing the challenges of studying dreams more subjectively. We suggest that hyperassociativity be studied further, with particular reference to the nature of the links between memory sources being identified over the course of the night.

AUTHOR CONTRIBUTIONS

Both authors contributed to the development of the ideas underlying the Research Topic concerning hyperassociativity and both engaged with the Topic as editors. CH drafted the editorial, on the basis of the manuscripts both authors had reviewed, discussed, and revised it prior to submission.

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A Novel Approach to Dream Content Analysis Reveals Links Between Learning-Related Dream Incorporation and Cognitive Abilities

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Can dreams reveal insight into our cognitive abilities and aptitudes (i.e., "human intelligence")? The relationship between dream production and trait-like cognitive abilities is the foundation of several long-standing theories on the neurocognitive and cognitive-psychological basis of dreaming. However, direct experimental evidence is sparse and remains contentious. On the other hand, recent research has provided compelling evidence demonstrating a link between dream content and new learning, suggesting that dreams reflect memory processing during sleep. It remains to be investigated whether the extent of learning-related dream incorporation (i.e., the semantic similarity between waking experiences and dream content) is related to inter-individual differences in cognitive abilities. The relationship between pre–post sleep memory performance improvements and learning-related dream incorporation was investigated (N = 24) to determine if this relationship could be explained by inter-individual differences in intellectual abilities (e.g., reasoning, short term memory (STM), and verbal abilities). The extent of dream incorporation using a novel and objective method of dream content analysis, employed a computational linguistic approach to measure the semantic relatedness between verbal reports describing the experience on a spatial (e.g., maze navigation) or a motor memory task (e.g., tennis simulator) with subsequent hypnagogic reverie dream reports and waking "daydream" reports, obtained during a daytime nap opportunity. Consistent with previous studies, the extent to which something new was learned was related (r = 0.47) to how richly these novel experiences were incorporated into the content of dreams. This was significant for early (the first 4 dream reports) but not late dreams (the last 4 dream reports). Notably, here, we show for the first time that the extent of this incorporation for early dreams was related (r = 0.41) to inter-individual differences in reasoning abilities. On the other hand, late dream incorporation was related (r = 0.46) to inter-individual differences in verbal abilities. There was no relationship between performance improvements and intellectual abilities, and thus, inter-individual differences in cognitive abilities did not mediate the relationship between performance improvements and dream incorporation; suggesting a direct relationship between reasoning abilities and dream incorporation. This study provides the first evidence that learning-related dream production is related to inter-individual differences in cognitive abilities.

Keywords: sleep, dreams, intelligence, memory, hypnagogic, cognitive ability

INTRODUCTION

The question "why do we dream?" has been a topic of debate throughout recorded history and, although the topic is widely studied, the answer remains highly contentious (Blagrove and Akehurst, 2000; Blagrove and Pace-schott, 2010) and still unresolved. Even more fundamental is the question of how dreams are constructed. It has been suggested that the nature of the cognitive qualities of dreams is an emergent property of an individual's intellectual strengths and weaknesses. Foulkes (1982, 1985) proposed that dreams manifest from fundamental cognitive functions, such as information processing, problem solving, and planning. Others have sought to understand dreams through identifying putative trait-like, psychometrically assessed correlates of dream production (e.g., memory capacity, personality traits, sleep characteristics, electroencephalography, and psychopathology). Surprisingly, experimental evidence to support a link between cognitive abilities and dream content remains sparse and inconsistent, thus, few conclusive links have been identified (Blagrove and Akehurst, 2000; Blagrove and Pace-schott, 2010). There are several reasons this could be the case. For example, previous work has focused exclusively on the dreams of rapid eye movement (REM) sleep, possibly overlooking any relationship between cognitive abilities and dreams during non-REM sleep. In comparison to REM sleep, relatively little is known about mental activity during non-REM sleep, and in particular, hypnagogic reverie. There is now recent and compelling evidence to suggest that novel waking-life experiences are incorporated into the content of non-REM dreams, particularly with the formation of new memories (Wamsley and Stickgold, 2010; Oudiette and Paller, 2013; Wamsley, 2014). Thus, suggesting that non-REM dream content can reflect the reprocessing of newly learned material. Yet, it remains to be investigated whether the extent of incorporation of newly formed memories into dream content is related to trait-like cognitive abilities. Such a link would demonstrate that dreams can serve as a window into our cognitive strengths or weaknesses, and help us understand the process of dream formation.

There is a large body of evidence suggesting that one of the functions of sleep is for memory consolidation, as reflected by performance improvements (e.g., from training to retest) over an intervening period of sleep (Maquet, 2001; Stickgold and Walker, 2005; Rasch and Born, 2013; Peigneux et al., 2015). More specifically, sleep has been shown to benefit memory for facts, places, and events [i.e., "declarative memory" (Plihal and Born, 1997; Smith, 2001; Gais et al., 2002; Gais and Born, 2004; Schabus et al., 2004; Clemens et al., 2005; Ellenbogen et al., 2006; Fogel et al., 2007b; Payne et al., 2012)], as well as for skills [i.e., "procedural memory" (Nader and Smith, 2003; Fogel and Smith, 2006; Fogel et al., 2007b, 2015; Barakat et al., 2011)]. More specifically, recent evidence from human neuroimaging studies suggest that after new learning, there is physiological reactivation of brain areas recruited during learning (Peigneux et al., 2003, 2006; Bergmann et al., 2011; Antony et al., 2012; Oudiette and Paller, 2013; Oudiette et al., 2013; Schönauer et al., 2014; Fogel et al., 2017). This reactivation of newly acquired memory traces is thought to underlie the process of sleep-related memory consolidation. In addition, single cell recordings in animal studies have shown that there is not only a reactivation of the same brain structures recruited during learning, but during sleep, there is a physiological replaying of the neural representation formed during waking exploration (Skaggs and McNaughton, 1996; Louie and Wilson, 2001; Lansink et al., 2009). In addition, recent converging evidence from humans suggest that behavioral (Oudiette et al., 2011; Uguccioni et al., 2013) and neuronal replay occurs after new learning during subsequent sleep (Buzsaki, 1989; Skaggs and McNaughton, 1996; Louie and Wilson, 2001; Girardeau et al., 2009). This reactivation and replay of newly acquired memories is reflected in the content of our dreams (Stickgold et al., 2000; Wamsley et al., 2010a,b; Kusse et al., 2012; Wamsley, 2014). Furthermore, sleep as compared to an equivalent period of wake, serves to support memory consolidation (Walker, 2005), and the process of consolidation is reflected in non-REM hypnagogic reverie (Wamsley et al., 2010a). However, relatively little is known about whether this is also reflected in the content of waking thought during mind wandering, i.e., "daydreaming." The characteristics of dreams as compared to daydream content differ; the later containing more references to preoccupations of waking life. Compared with daydreams (van Rijn et al., 2018), non-REM dreams during a daytime nap are less emotionally intense, have fewer sensory experiences, whereas as compared to daydreams, REM dreams are more bizarre with heightened sensory experiences (Carr and Nielsen, 2015), and are a time of increased mind wandering (Fox et al., 2013). However, the incorporation of learning-related content of daydreams vs. dreams remains to be directly compared. Taken together, these studies suggest that dream incorporation reflects memory consolidation processes related to the reactivation and replaying of neuronal events that took place during learning.

The notion that daytime experiences and newly acquired memories are incorporated into the content of dreams is not new. However, several methodological hurdles have presented a challenge to the objective, scientific investigation of dreams. For example: (1) only certain types of experiences (e.g., engaging, emotional, and autobiographical) are robustly incorporated into dreams (Stickgold et al., 2000; Malinowski and Horton, 2014a,b), (2) the type and timing of sleep when dream reports are collected is important for identifying learning-related incorporation (Nielsen et al., 2004; van Rijn et al., 2015), (3) the objective quantification of dream content, until very recently (Amini et al., 2011; Horikawa et al., 2013; Wong et al., 2016) has been limited to subjective assessment of verbal dream reports, and (4) the measurement of the semantic relationship between waking experiences and verbal dream reports (i.e., incorporation) has only been subjectively assessed by comparing behavior to dream reports, as opposed to comparing verbal reports of the learning experience to verbal reports of the subsequent dream experience (Wamsley et al., 2010a,b).

As mentioned above, only certain types of experiences are incorporated into dreams. Early studies investigating the influence of daytime experiences on dream content (Foulkes and Rechtschaffen, 1964; Witkin and Lewis, 1965; Cohen, 1971; De Koninck and Koulack, 1975; Goodenough et al., 1975), used passive and less immersive stimuli such as images and films. Surprisingly, these studies did not identify clear evidence of dream incorporation. It was subsequently found that dream content could be more easily manipulated and detected with the use of novel, immersive, and impactful experiences (De Koninck and Koulack, 1975; Koulack et al., 1985; Corsi-Cabrera et al., 1986; De Koninck et al., 1988, 1990). An important milestone in understanding the phenomena of dream incorporation came from Stickgold et al. (2000) where participants played a variation of the highly engaging video game 'Tetris' before sleep. They found that both normal individuals and amnesiacs had similar dream reports, directly incorporating elements of the game into their dreams, even though the amnesiacs did not recall playing the game. Similar findings come from other highly engaging or emotionally arousing tasks such as downhill skiing arcade games (Wamsley et al., 2010a), navigation of a virtual 3D environment (Wamsley et al., 2010b; Solomonova et al., 2015) and stressful/emotionally arousing situations (De Koninck and Koulack, 1975; Koulack et al., 1985; Malinowski and Horton, 2014a). Thus, not all daytime experiences are robustly incorporated, or easily identified in post-learning dream content. Consistent with previous studies, here, highly engaging tasks were employed to maximize the likelihood of identifying dream incorporation.

Not only does the type of experience impact dream incorporation, but the type and timing of the sleep where the dream reports are collected also influence the nature of the reported dream content. While REM sleep is most commonly associated with dreaming (Aserinsky and Kleitman, 1953; Dement and Kleitman, 1957), it is now becoming increasingly clear that some form of dreaming exists in all stages of sleep (Foulkes, 1962; Palagini et al., 2004; Suzuki et al., 2004; McNamara et al., 2010; Oudiette et al., 2012); suggesting that sleep without dreams is akin to wake without thought. For example, hypnagogic reverie during the lighter stages of non-REM sleep (e.g., stages 1 and 2 sleep), traditionally thought not to contain dreams, have been found to contain vivid dreamlike content (Foulkes and Vogel, 1965; Vogel et al., 1972; Vogel, 1991) and most recently, rich incorporations of daytime experiences (Wamsley et al., 2010a,b). Furthermore, several important factors have been identified that can be leveraged to facilitate the study of dreams in non-REM sleep (Vogel, 1991; Nielsen, 2000; Nielsen et al., 2004; Wamsley et al., 2010a), including: (1) allowing only a short delay between the daytime experience and the dream report (e.g., reports collected "early" vs. "late" in the sleep episode), (2) by collecting dream reports after only short bouts of sleep (e.g., short $\leq$15 s vs. longer $\geq$45–75 s, or $>$120 s), and (3) collecting reports from the lighter stages of non-REM sleep (e.g., stage 1 and following the first indications of stage 2 sleep) as compared to deeper slow wave sleep (e.g., SWS). Thus, collecting early dream reports, following short bouts of light non-REM sleep, maximizes the chances of obtaining robust, frequent and direct learning-related dream incorporations (Nielsen, 2017).

Not only does sleep serve to support sleep-related memory consolidation, there is also accumulating evidence suggesting that trait-like inter-individual differences in the characteristics of non-REM sleep (e.g., sleep spindles) relate to trait-like cognitive abilities (Schabus et al., 2006; Bódizs et al., 2008; Fogel and Smith, 2011; Geiger et al., 2011; Gruber et al., 2013; Hoedlmoser et al., 2014; Ujma et al., 2014; Fang et al., 2017). Specifically, this research has found that spindles are highly correlated with reasoning and problem-solving skills (e.g., the ability to employ logic and identify complex patterns; Schabus et al., 2006; Fogel et al., 2007a; Fogel and Smith, 2011; Fang et al., 2017). Given that spindles have also been identified as indices of reactivation of recently acquired information (Bergmann et al., 2011; Fogel et al., 2014), it is probable that this spindle-related reprocessing during non-REM sleep, may be reflected in the content of dreams. However, it remains to be explored whether the extent of learning-related dream incorporation is correlated with inter-individual differences in intellectual abilities. The investigation of the relationship between the extent of dream incorporation following new learning and intellectual abilities may serve as a means to disentangle the links between memory consolidation, dreaming, and cognitive abilities.

Here, we propose to ask the question: are inter-individual differences in the extent of the incorporation of newly learned experiences into dreams associated with waking intellectual abilities? A mediation model was used to test whether the relationship between learning and the incorporation of daytime experiences into dreams can be explained by inter-individual differences in cognitive ability. We predicted that: (1) the extent of memory consolidation will be related to dream incorporation, particularly for early dream reports, when learning-related dream incorporations are more direct (Wamsley et al., 2010a), (2) learning-related dream incorporation will be positively correlated with cognitive abilities, such as reasoning abilities (which have been linked to spindles during non-REM sleep), (3) this relationship may also be stronger during early dream reports when incorporations are more robust, and (4) given that sleep as compared to an equivalent period of wake, serves to support memory consolidation (Walker, 2005), and the process of consolidation is reflected in non-REM hypnagogic reverie (Wamsley et al., 2010a), dream imagery will have greater learning-related incorporation than wake imagery. Finally, (5) a mediation analysis was planned to test whether the relationship between the extent of performance improvements (from training to retest, representing the extent of memory consolidation) and dream incorporation were mediated by inter-individual differences in cognitive abilities.

This study will help to provide insight into the nature of dream formation as it relates to cognitive abilities, such as the capacity for reasoning, problem solving, the use of logic (i.e., "fluid intelligence") or the application of existing knowledge (i.e., "verbal intelligence") thus supporting Foulkes' notion of a close link between cognitive capacity and the level of sophistication in dream production.

MATERIALS AND METHODS

Ethics Statement

All participants were given a letter of information, gave written informed consent prior to participation and were financially compensated for their participation. This study was carried out in accordance with the recommendations of Tri-Council Policy Statement for the Ethical Conduct for Research Involving Humans. This research was approved by the Western University Health Science Research Ethics Board, London, ON, Canada.

Procedure

See **Figure 1** for an overview of the experimental design. All participants were initially screened to verify that they met the inclusion criteria (see section "Participants and Screening" for details). Each participant underwent two, in-laboratory PSG recordings including an initial acclimatization and screening nap, followed one week later by the experimental nap. For each afternoon, the participant would arrive at the sleep laboratory at 12:00 PM where they were prepared for PSG recording (see section "Polysomnographic Recordings" for details). Following this, on the experimental afternoon, participants were trained on either the spatial navigation task (*N* = 12; see section "Spatial Navigation Task" for details) or the tennis task (*N* = 12; see section "Tennis Task" for details). Participants were then asked to close their eyes and mentally rehearse the task that they had just performed for 30 s, followed by 30 s of rest, where they imagined themselves singing the "alphabet" song. This mental rehearsal and rest alternated a total of 10 times. The rest condition was used to avoid continuing to rehearse the task, reduce mental fatigue, or mind wandering by the participants by having them all imagine themselves singing a commonly known song. Following the mental rehearsal sessions, participants verbally provided a "wake report" describing in detail the mental rehearsal of the task (see section "Verbal Reports" for details). Next, participants were given a 90-minute daytime nap opportunity with PSG monitoring and recording. During this nap, participants were monitored by an RPSGT and woken up after brief periods (> 10 s) of non-REM sleep or wake and asked to provide "dream reports" or "daydream reports" (see section "Verbal Reports" for details). Each subject included in the data analysis had a minimum of *N* = 8 dream reports, and *N* = 2 daydream reports. All verbal reports were recorded via audio recording and subsequently transcribed. The extent of incorporation between the wake report and each dream report or daydream report was quantified using a novel approach (See section "Verbal Report Analysis" for details). Following the nap opportunity, participants were retested on the same task as before. Testing on the Cambridge Brain Sciences (CBS) Trials (see section "Cognitive Abilities Testing" for details) took place between the hours of 9:00 AM and 9:00 PM the following day at their optimal time of day, after completion of the experimental protocol so as not to influence the sleep or dream content during the experimental sessions.

Participants and Screening

A total of 24 healthy young adults (20 female; mean age = 23.3 ± 4.0 years; age range: 20 to 35 years) participated in the study. Sample sizes were determined based on previous studies, and power calculated, where possible, using G*Power for Mac version 3.1 (Faul et al., 2007, 2009). A recent study by our group using the same cognitive tests as the current study (Fang et al., 2017) found robust associations in a sample size of *N* = 24, replicating previous findings in smaller samples (Fogel and Smith, 2006; Fogel et al., 2007a) (n.b., based on power calculation for correlation with α (two-tailed) = 0.05, β = 0.20, effect size = 0.56, *N* = 22 required). To our knowledge, only one study has employed a similar approach to dream content analysis using WordNet (Horikawa et al., 2013), in as few as *N* = 3 individuals; albeit it should be noted they employed a

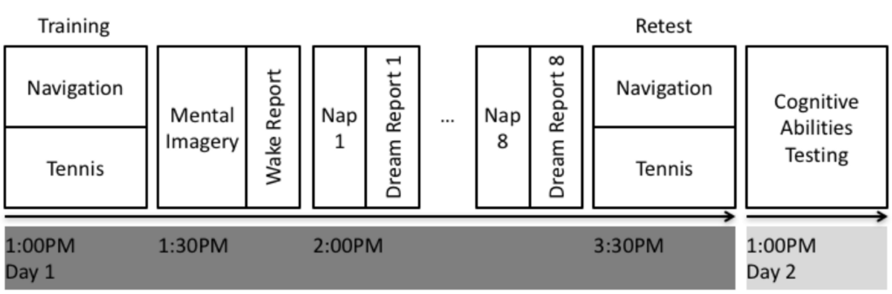

FIGURE 1 | Experimental design. On day 1, subjects performed either the spatial navigation or tennis task for approximately 30 min. They were then asked to mentally rehearse their experience and subsequently provide a detailed wake verbal report of the mental rehearsal. Subjects then underwent PSG monitoring while attempting to fall asleep. Subjects were awoken periodically after signs of light non-REM sleep to provide a dream report or after an equivalent interval of wakefulness to provide a daydream report. Subjects were then retested on the same task after the nap. Finally, at the completion of the experimental protocol, subjects completed the CBS Trials test battery the next day.

very different statistical approach to the current study. Similar protocols to the present study (Wamsley et al., 2010a) have detected robust dream learning-related incorporation in $N = 16$ participants (based on power calculation for paired t-test with α (2-tailed) = 0.05, $\beta = 0.20$, effect size = 3.3, $N = 4$ required). Thus, similar to previous reports, a sample size of $N = 24$ was considered to be adequate to detect the cognitive correlations, and $N = 12$ (per task condition) to detect behavioral, cognitive and dream content effects.

Potential participants underwent an initial telephone screening interview and were excluded if they reported they were not in good health, left-handed, considered themselves to be a poor sleeper, had an irregular sleep schedule (slept outside of 10:00 PM to 9:00 AM), had a body mass index >30, were diagnosed with a sleep disorder, worked as a shift worker, took medication known to interfere with sleep, or had a history of psychiatric or mental illness, head injury, or seizure. To be included, interested participants had to score <10 on the Beck Depression Inventory (Beck et al., 1974) and the Beck Anxiety Inventory (Beck et al., 1988), and have no indications of a sleep disorder based on the Sleep Disorders Questionnaire (Douglass et al., 1994).

In addition to these criteria, participants underwent a 90-minute polysomnographic (PSG) recording that served as an acclimatization and sleep disorder screening nap from approximately 1:00 PM to 2:30 PM. The screening nap included electroencephalogram (EEG; from scalp locations Fz, Cz, Pz, and Oz), electrooculogram (EOG; from the left and right outer canthus of the eye), electromyogram (EMG; from the submental chin muscles and anterior tibialis muscle of each leg), respiration (via thorax and abdomen respiratory effort belts), electrocardiogram (ECG; from below each clavicle), and blood oxygen saturation (via a finger probe placed on the index finger of the right hand). Screening nap recordings were manually scored by a single, expert Registered Polysomnographic Technologist (RPSGT) in accordance with clinical scoring guidelines established by the American Academy of Sleep Medicine (Iber et al., 2007). Participants were excluded from further participation in the study if the results of their screening nap revealed greater than 5 respiratory events per hour of sleep or greater than 10 periodic leg movements per hour of sleep.

To verify that participants maintained a regular sleep schedule for the duration of their participation in the study, they were also asked to wear an 'Actiwatch' (Philips Respironics Inc., Andover, MA, United States; a wrist-worn accelerometer, to measure sleep-wake-related limb movements) and to complete a log of their daily activities and sleep habits. Participants were excluded from further participation in the study if the actigraphy data or activity and sleep log identified non-compliance with the instructions to maintain a regular sleep-schedule prior to in-laboratory testing.

Polysomnographic Recordings

Embla Titanium (Natus, Pleasanton, CA, United States) PSG systems were used to perform in-laboratory sleep recordings. Physiological data were recorded at a sampling rate of 512 Hz, with a high pass filter = 0.15 Hz. EEG (from scalp locations: F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, and Oz), EOG (from the left and right outer canthus of the eye), and EMG (from the submental chin muscles) recordings were taken using gold-plated electrodes applied to the skin. Each EEG and EOG channel was recorded and re-referenced offline to an average mastoid reference (M1 and M2). The EMG channel was recorded as a bipolar derivation. Sleep stages were visually scored in 10-second epochs by a single, expert RPSGT in accordance with standard sleep stage scoring criteria (Iber et al., 2007) using RemLogic analysis software (Natus, Pleasanton, CA, United States).

Behavioral Testing

Spatial Navigation Task

A spatial navigation task (Sutton et al., 2014) was used to train and then retest a sub-group of the participants (spatial navigation condition, $N = 12$) before and after a daytime nap opportunity. This task was chosen because the neural correlates of mental imagery for similar tasks have been previously characterized (Owen et al., 2006; Monti et al., 2010; Cruse et al., 2011) and is similar to previous studies investigating the role of sleep (Peigneux et al., 2004; Orban et al., 2006) and dreams (Wamsley et al., 2010b) for spatial learning using 3D virtual environments. In-house software was developed using a modified version of the 3D first person video game, "Team Fortress" (Valve Corporation, Bellevue, WA, United States), for PC. Participants navigated through a 3D environment meant to resemble an Italian village in first person view mode. The virtual environment consisted of six distinct start and goal spatial locations (see Sutton et al., 2014 for details) including a coffee shop terrace, a restroom entrance, a derelict vehicle, bikes on a bike rack, a fruit market, and an Italian flag painted on a wall of a courtyard. For each trial, participants began navigating the maze from one of the start locations and were instructed to navigate to a predetermined goal location (e.g., "find the coffee shop"). The start and goal locations were pseudo-randomly determined for each trial. Participants were instructed to use the keyboard keys W, A, S, and D to navigate forward, left, back, and right, respectively. As well, the left and right arrow keys rotated their point of view of the environment leftward or rightward (but not up or down, in order to restrict the degrees of freedom in movement to simplify the demands required to navigate the environment). Participants were instructed that the objective of the task was to navigate through the environment as quickly as they could, using the shortest route possible to find the pre-determined goal location. Participants completed a total of 30 trials in the training session and 6 trials in the retest session. The number of trials was determined so that the training session would last approximately 30 min in total. Performance was measured in terms of speed (i.e., distance per time taken from the start to the goal location). This measure excluded backtracking away from the target. Offline performance improvements from training to retest with an intervening nap period, were measured as the mean difference in speed from the end of the training session (mean of last two trials) to the start of the retest session (mean of first two trials).

Tennis Task

In order to ensure that the extent of the incorporation was specific to the waking experiences of the participants, and not some epiphenomena of similarity between individuals' reports, another learning experience distinct from spatial navigation was employed. Grand Slam Tennis (Electronic Arts, Redwood City, CA, United States) for the Nintendo (Kyoto, Japan) Wii video game console (with Wii tennis racquet remote) was used to train and then retest another group of the participants (Tennis condition, $N = 12$) before and after a daytime nap opportunity. This task was chosen as the neural correlates of mental imagery for similar tasks have been previously characterized (Owen et al., 2006; Monti et al., 2010; Cruse et al., 2011) and is similar to previous studies investigating the role of sleep (Peigneux et al., 2004; Orban et al., 2006) and dreams (Wamsley et al., 2010b) in immersive game simulations. The experimenter demonstrated the correct position for the participant to stand (e.g., 2 m from the 2.1 m × 1 m image projected on the wall of the testing room with their feet 0.3 m apart from one another), the appropriate grip for holding the "tennis racquet" (e.g., the tennis racquet-shaped motion sensitive game controller), and the manner to serve and swing the racquet. The participants were instructed "to hit the ball over the net and into the opponent's court in such a way that the opponent is not able to play a good return." Each testing session followed the normal rules of the game of tennis. In the training session, participants played a match of 20 games. After the nap opportunity, the retest session consisted of a match of five games. In both the training and retest session, participants were always serving (i.e., service did not alternate between participant and opponent). Each game consisted of a series of rallies and was completed when one of the players won four points (i.e., "game point"). Note that in the case of a tie (i.e., "deuce"), the game was won when either the participant or the opponent won two rallies in a row, for a total of five points won. The number of training games was determined so that the play time of the session, similar to the spatial navigation task, would last approximately 30 min in total. Performance for each game was measured in terms of points won per number of rallies played, thus reflecting the efficiency of their win per game. Offline performance improvements from training to retest with an intervening nap period, were measured as the mean difference in points won per rally from the end of the training session (mean of last two trials) to the start of the retest session (mean of first two trials).

Verbal Reports

Verbal Report Collection

In order to allow participants the opportunity to practice verbally reporting their dreams prior to in-laboratory testing, participants were required to create an audio recording of their verbal dream reports upon awakening each morning for 1 week prior to the training day. On the training day, three distinct types of verbal reports were collected including: (1) a mental rehearsal "wake report," (2) "dream reports," and (3) "daydream reports." The wake report was obtained after a 10-minute mental rehearsal session of the task that they were previously trained on (see section "Behavioral Testing"). Participants were instructed to provide a descriptive verbal report of the task-related mental imagery from the rehearsal sessions. This was also combined with a verbal report describing the lab environment in which they were trained on the task. The "dream reports" and "daydream reports" were obtained throughout the 90-minute daytime nap opportunity. During this nap opportunity, participant's polysomnographic recordings were visually monitored continuously by an expert polysomnographic technologist and woken up before entering stage 2 sleep, to collect eight dream reports (following non-REM) interspersed throughout the nap opportunity, and as many daydream reports (following wake) as possible. Specifically, participants were allowed to get least 10 s of stage 1, and woken up immediately upon the first signs of stage 2 sleep (indicated by the presence of the first sleep spindle or k-complex). Participants were then asked to provide a dream report by verbally describing, in as much detail as possible, "*what was just going through your mind*" while asleep. The first four dream reports were categorized as "early" and the last 4 dream reports were considered "late" dreams. The "daydream reports" were also collected during the 90 min nap opportunity, however, they were collected after a minimum of 10 s of wake, indicated by visual inspection of the ongoing polysomnographic recording, while the subject was attempting to fall back to sleep, but still awake. It should be noted that there were not enough daydream reports available to divide into early and late, however, we had no a-priori hypotheses from the literature to make such a comparison. A minimum of at least one dream report was collected prior to collecting the daydream report. See **Figure 2** for representative dream examples collected in the different conditions (e.g., early, late, and daydreams).

Verbal Report Analysis

Advancements from natural language processing and computational linguistic approaches, in combination with large databases of the English language (e.g., WordNet, a database of semantically disambiguated word senses), can provide a means to objectively interpret verbal dream reports, and also be applied to quantify the extent of dream incorporation. Dream incorporation was measured as the average degree of semantic similarity between the wake report, and: (1) the dream reports (i.e., the reports obtained following periods of sleep), and (2) the daydream reports (i.e., the reports obtained during periods of wake while attempting to fall asleep). Semantic similarity between these sets of verbal reports was computed from WordNet 3.0 (Miller, 1995; Fellbaum, 1998) using tools included in the Natural Language Toolkit (NLTK) for Python (Perkins, 2010). WordNet is a publicly available lexical database of the English language. The WordNet database is a manually curated collection of 155,287 words. WordNet is structured such that each word is grouped into 117,659 sets of synonyms, or "synsets" (i.e., an interconnected hierarchy of groups of synonyms and their brief definitions). Much like a dictionary, each word is represented in terms of its part of speech (e.g., noun, adjective, verb, adverb), meaning (i.e., senses) for polysemous words, and a brief definition (i.e., gloss) using one or more examples. Each word can be a member of more than one synset. In addition, much like a thesaurus, WordNet contains semantic relations (e.g., synonyms, antonyms, parent-child relations or "hyponyms," and part-of relations or "meronyms"). This information is organized into a hierarchical structure that can

MENTAL REHEARSAL:

Navigation condition: *"I see all the chairs at the coffee shop and I see there is like a bannister beyond the coffee shop chairs and I walk towards the chairs and then there's a coffee cup on the table and I look to my right and then there is the coffee shop sign on the wall..."*

Tennis condition: *"...I am standing on the tennis court and I can see that the court turf is green but it's not a sunny day... I throw the ball up and I hit it with the tennis racquet and it goes clear over the net and properly served to her and she hits it back and it comes back towards me bounces once and I return it"*

EARLY DREAMS:

Navigation condition: *"I was sitting at a table. Playing something that looked like tic tac toe but with different symbols. It was a round table. This might sound weird, but I think I was sitting in the cafe."... "I was thinking about being at the coffee shop in my dream... everyone... like a bunch of people... being there... and people are standing on the tables..."*

Tennis condition: *"I was just thinking about... there is a path near the creek that is right near the tennis court... and I was thinking that I might go down there later this week with my family..."*

LATE DREAMS:

Navigation condition: *"... a series of shadow puppets on the wall... one was a dog... they were backed by a yellow lamp..."*

Tennis condition: *"... yeah it's a commercial for some kind of energy drink maybe... or maybe an alcoholic drink... I'm not sure exactly what I was watching on TV... that's mainly what I remember... very, very tall drink... the colors were maybe green and blue and grey from what I was seeing on the television..."*

DAYDREAMS:

Navigation condition: *"I was thinking how about what I was going to do when I finish here.. and how I was going to go to the library as well... and what the weather is right now."*

Tennis condition: *"I was thinking about getting ready for school and all the stuff I have to do this week..."*

FIGURE 2 | Excerpts from representative examples of wake mental rehearsal, early, late, and daydream reports. Note that in these representative examples, that early dreams contain direct incorporations from the daytime experience of navigating to the goal destinations of the virtual maze (e.g., the café), or the objects in the environment (e.g., a round table), and in another example, mention a tennis court. By contrast, late dreams appear to have incorporations from the lab environment (e.g., references to screens). A description of the lab environment was included in the wake reports to account for non-task specific, but laboratory context-related incorporations. In contrast, the daydream tended to contain preoccupations of the day, rather than incorporations of past task or lab environment elements.

be represented as a network (i.e., hypernym tree) of words contained within synsets (see **Figure 3** for an example of a highly simplified conceptual representation of the WordNet structure illustrating the semantic distance between the synsets "tennis" and "squash," and between the more distantly related synsets "ball" and "tennis"). By representing synsets in a hypernym tree, the semantic distance (i.e., synset similarity) can be calculated using Wu–Palmer Similarity (Wu and Palmer, 1994), a scoring method to compute semantic similarity based on how similar word senses are to one another and where synsets occur relative to one another in the hypernym tree, with scores ranging from 0 (no semantic relationship) to 100 (completely synonymous). The Wu-Palmer method available in the NLTK is advantageous as it can measure similarity between different parts of speech and can account for part-of relations (Wu and Palmer, 1994; Warin, 2004; Petrakis et al., 2006). The Wu–Palmer Similarity computes shortest number of edges from one synset to another synset within the hierarchical WordNet structure, by also considering the depths of the two synsets in the WordNet hierarchy, along with the depth of the least common subsumer (lcs), as follows:

$$\text{Wu–Palmer score} = 2 \times \text{depth (lcs)}/[\text{depth (s1)} + \text{depth (s2)}]$$

To perform this analysis, first, the audio from the reports was transcribed into plain text (*.txt) files. All quantitative analyses were coded in Python and were carried out using the NLTK and WordNet. Next, the transcribed verbal reports were tokenized (i.e., parsed) using the NLTK into words for only the meaningful parts of speech, including: nouns, adjectives, verbs, and adverbs. After programmatically removing punctuation and stop-words (i.e., common words that do not contribute to the meaning of a sentence), each word was used to look up the corresponding synsets in the WordNet hierarchy database, thereby creating a list of synsets corresponding to the words in each verbal report.

Note that a given word can belong to several synsets, and thus, all synsets for each word from the corpus of text were included in the Wu–Palmer Similarity analysis. Finally, the semantic distance (using Wu–Palmer Similarity) from each possible pair of synsets corresponding to a given word to another was calculated using the NLTK iteratively and exhaustively between pairs of synsets from the wake reports and the synsets of each dream report. This was also done between the wake reports and daydream reports. Then, an average of the pairwise Wu-Palmer calculations was calculated in order to measure the average (i.e., overall degree) of incorporation of the waking experience into the content of each set of dreams (early and late) and daydreams. In other words, this incorporation score reflects the average Wu Palmer similarity scores between all wake-dream report pairs of synsets. A score of 100 would represent complete identity between all the synsets from the wake report and all the synsets from the dream reports (n.b., a highly unlikely scenario), and zero would represent no semantic relationship between the synsets of the wake report and the synsets of the dream reports. For example, an incorporation score of 15 for early dreams, would mean that the average of all Wu–Palmer Similarity scores comparing synsets in the wake report to synsets in early dream reports was 15.

Cognitive Abilities Testing

The CBS Trials battery (Hampshire et al., 2012) is composed of 12 online computerized cognitive tests that were designed based on well-established paradigms from the cognitive neuroscience literature (see: Hampshire et al., 2012) for detailed descriptions of the 12 individual tests). The CBS Trials can be used to assess a wide variety of cognitive abilities, which can be factored together to evaluate three higher-order cognitive domains described as "Verbal," "Reasoning," and "STM" subscales, derived from a data driven approach using factor analysis, conducted in a large population from a previous study (Hampshire et al., 2012). The Verbal subscale is composed primarily of verbal reasoning (Baddeley, 1968), color-word remapping (Stroop, 1935), and the digit span test (Wechsler, 1981). The Reasoning subscale is composed primarily of deductive reasoning (Cattell, 1940), spatial rotation (Silverman et al., 2000), feature match (Treisman and Gelade, 1980), spatial planning (Shallice, 1982), and the interlocking polygons test (Folstein et al., 1975). Lastly, the STM subscale is composed primarily of visuospatial working memory (Inoue and Matsuzawa, 2007), spatial span (Corsi and Micheal, 1972), paired associates (Gould and Brown, 2005), and the self-ordered search test (Collins et al., 1998). Raw scores from each of the 12 tests were normalized using the age matched population mean and standard deviation obtained from a large (N = 44,600) population (Hampshire et al., 2012). Next, to combine the subtests into their respective higher-order subscales, the normalized test scores were re-weighted using factor loadings from Hampshire et al. (2012), and then the respective tests which compose each factor-weighted subscale were averaged to create the Verbal, Reasoning, and STM subscales. Finally, the sub-test scores were transformed to a mean of 100 and a SD of 15 so that test scores were readily comparable to results from similar studies by our group and others that employed test batteries which assess reasoning and verbal abilities, such as the MAB-II (Fogel and Smith, 2006, 2011; Fogel et al., 2007a).

Statistical Analyses

All statistical analyses were carried out using SPSS Statistics version 22 (IBM, Armonk, NY, United States). First, to confirm whether participants did in fact exhibit performance improvements after the nap retention period, paired t-tests were used to investigate performance improvements from the last two trials of the training session to the first two trials of the retest session. As well, independent t-tests were used to establish if there were any differences between the participants within the

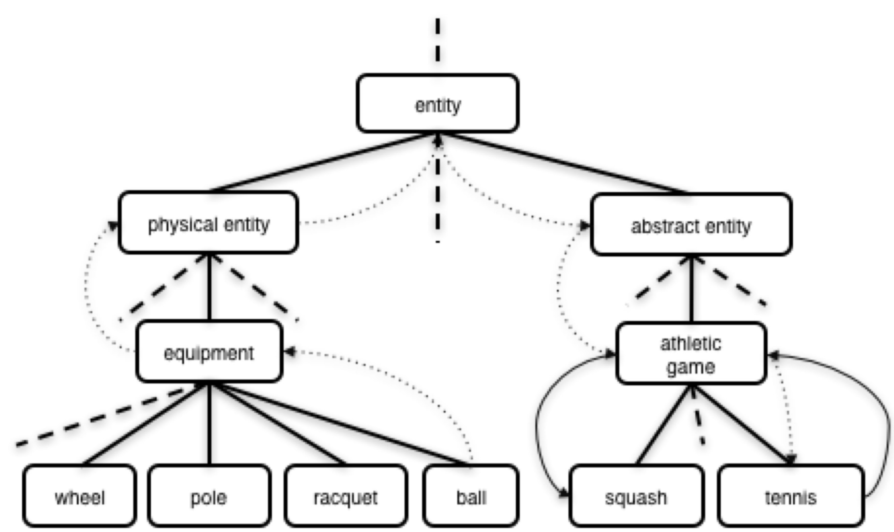

FIGURE 3 | A highly simplified conceptual representation of the WordNet hierarchy. Examples of the shortest path between the more closely related synsets "tennis" and "squash" (solid arrows) versus the path between the more distantly related synsets "ball" and "tennis" (dotted arrows) in a simplified WordNet hierarchy.

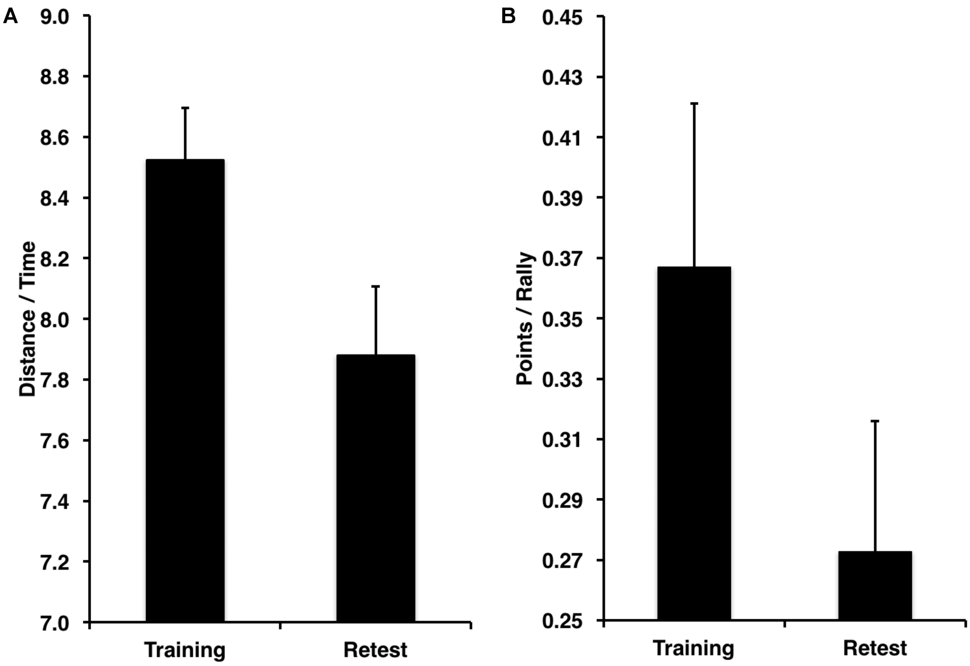

FIGURE 4 | Significant performance improvements from training to retest in terms of speed for the **(A)** spatial navigation task in distance traveled toward the target (a.u.) per amount of time in seconds, **(B)** and number of points won per number of rallies played.

tennis and spatial navigation conditions in terms of the semantic similarity between their wake and dream reports and between their wake and daydream reports.

To systematically test the hypothesis of whether the relationship between dream incorporation and the extent of performance improvements (from training to retest, representing the extent of memory consolidation) were mediated by inter-individual differences in cognitive abilities, a well-established four-step mediation analysis procedure using multiple regression (as recommended by Judd and Kenny, 1981; James and Brett, 1984; Baron and Kenny, 1986) was employed. Step 1 regressed each dependent variable for performance improvement in separate analyses on the independent variables, dream incorporation (early, late, and daydreams), to test whether there was a significant relationship between dream incorporation and performance improvements. Step 2 regressed each mediator variable for dream incorporation (early, late, and daydreams) on the independent variables, cognitive abilities (Reasoning, Verbal, and STM), to confirm whether there was a significant relationship between dream incorporation and cognitive abilities. Step 3 regressed each dependent variable, for performance improvement in separate analyses on the mediator variables for cognitive abilities (Reasoning, Verbal, and STM) to determine whether there was a significant relationship between cognitive abilities and performance improvements. If Steps 1–3 were satisfied, then mediation was possible and would be tested in Step 4. If Step 4 was viable, each dependent variable for performance improvements was regressed in separate analyses on the mediator variables for cognitive abilities (Reasoning, Verbal, and STM) while controlling for dream incorporation (early, late, and daydreams) to determine whether the relationship in Step 1 was either partly or fully mediated by cognitive abilities. The purpose of Steps 1–3 was to establish that zero-order relationships existed among the various factors that may account for the relationship between dream incorporation and performance improvements. If one or more of these relationships were not statistically significant, then mediation was not possible, or statistically unlikely (Judd and Kenny, 1981; James and Brett, 1984; Baron and Kenny, 1986). All statistical results were considered significant at $p < 0.05$ for the multiple regression, and if significant, the results were further investigated by inspecting the partial coefficients to examine which of the independent variables uniquely accounted for variability in the dependent variable in the model.

RESULTS

Performance Improvements

Performance improved from the training to the retest session for the spatial navigation task (**Figure 4A**) in terms of speed [distance/time from the start to the goal location; $t(11) = 3.99$, $p < 0.001$, $D = 2.78$]. Similarly, performance improved from training to retest for the tennis task (**Figure 4B**) in terms of points won per number of rallies played [$t(11) = 2.13$, $p = 0.027$, $D = 2.07$].

Given that participants were randomly assigned to the two task conditions and for the purposes of this study, there were no hypotheses about the task-specific nature of the incorporations, this study only assessed the relationship of the extent of the incorporation with performance improvements and also with cognitive abilities, irrespective of the particular daytime experience (e.g., tennis or spatial navigation), or lab environment. Thus, for or all subsequent analyses, unless stated otherwise, the tennis and spatial navigation conditions are considered together ($N = 24$).

Incorporation of Waking Experiences Into Dreams and Daydreams

There was no difference between the spatial navigation ($N = 12$) and tennis ($N = 12$) conditions (**Table 1**) in terms of the extent of semantic similarity, reflecting incorporation, between the wake report and early dream reports [$t(22) = 1.65$, $p = 0.113$, $D = 0.68$], late dream reports [$t(22) = 0.38$, $p = 0.705$, $D = 0.16$], all dream reports combined [$t(22) = 1.64$, $p = 0.115$, $D = 0.67$], or daydream reports [$t(22) = 0.44$, $p = 0.667$, $D = 0.22$]. In addition, the magnitude of early dream incorporation did not differ from late dream incorporation [$t(23) = 0.89$, $p = 0.382$, $D = 0.18$]. Incorporation for early dreams [$t(22) = 5.13$, $p < 0.001$, $D = 1.304$], late dreams [$t(22) = 3.59$, $p = 0.003$, $D = 0.91$] and all dream reports combined [$t(22) = 4.69$, $p < 0.001$, $D = 1.21$] were significantly higher than daydream incorporation. Together, these results suggest that the extent of dream incorporation did not differ between the spatial navigation and tennis conditions, and that dream report content was more similar, in terms of extent of incorporation, than daydream content (see **Figure 2** for illustrative examples).

To assess the specificity of the incorporation, a supplementary analysis was conducted to measure the semantic similarity (between wake and dream reports) for each individual within a condition to all other individuals within the same condition, and another analysis to measure the semantic similarity for each individual to all other individuals in the other condition. Within-condition semantic similarity was higher than between-condition similarity for dreams in the tennis [$t(11) = 5.56$, $p < 0.001$, $D = 1.61$] and spatial navigation condition [$t(11) = 3.98$, $p = 0.002$, $D = 1.15$]. Suggesting that semantic relatedness was higher between individuals within the same condition than between individuals in different conditions. Thus, the extent of incorporation was not some epiphenomenon of relatedness between an individual's wake report and their own subsequent dream (or daydream) report.

TABLE 1 | Mean dream and daydream incorporation in the spatial navigation and tennis conditions and collapsed across conditions (all), where 0 = no semantic relationship and 100 = completely synonymous.

	Spatial navigation ($N = 12$)		Tennis ($N = 12$)		All ($N = 24$)	
	M	**SD**	**M**	**SD**	**M**	**SD**
Early	14.97	1.56	13.89	1.68	14.43	1.68
Late	14.30	1.32	14.07	1.65	14.18	1.47
Mean	14.77	1.35	13.77	1.63	14.27	1.55
Daydream	12.54	1.58	12.08	2.58	12.34*	2.01

Indicates significantly different from at $p < 0.05$ from early, late, and mean dream incorporation for all (N = 24 subjects).

The Relationship Between Dream Incorporation and Memory Performance, and Mediation by Inter-individual Differences in Cognitive Ability

Step 1: Dream Incorporation and Performance Improvements

Multiple regression was used according to established procedures to test for mediation (Judd and Kenny, 1981; James and Brett, 1984; Baron and Kenny, 1986) to investigate the relationship between performance improvements with dream incorporation (**Figure 5**). This analysis revealed that early dream incorporation was correlated with performance improvements

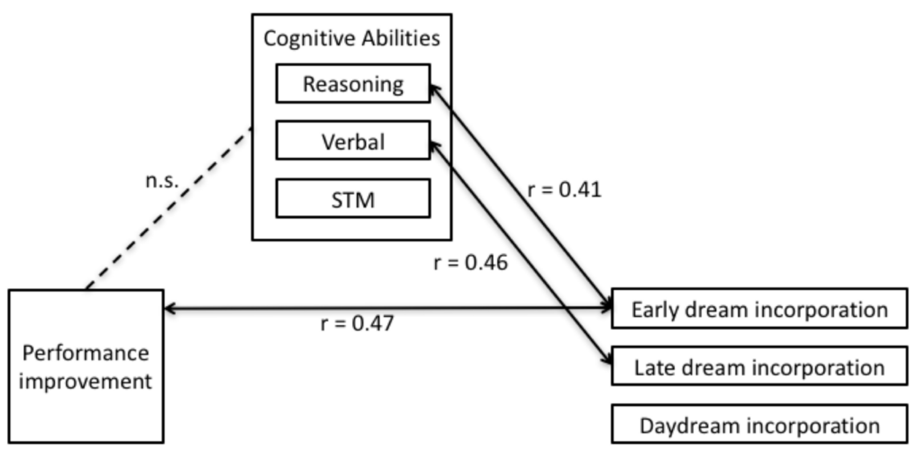

FIGURE 5 | Inter-relationships between performance improvements, dream incorporation and cognitive abilities. Improved performance was correlated with early dream incorporation ($r = 0.47$), but not late dream incorporation or daydream incorporation. Early dream incorporation was directly correlated with reasoning ($r = 0.41$), but not verbal abilities or STM. Late dream incorporation was directly correlated with Verbal ($r = 0.46$) but not reasoning abilities or STM. There was no significant direct relationship between performance improvements and intellectual ability.

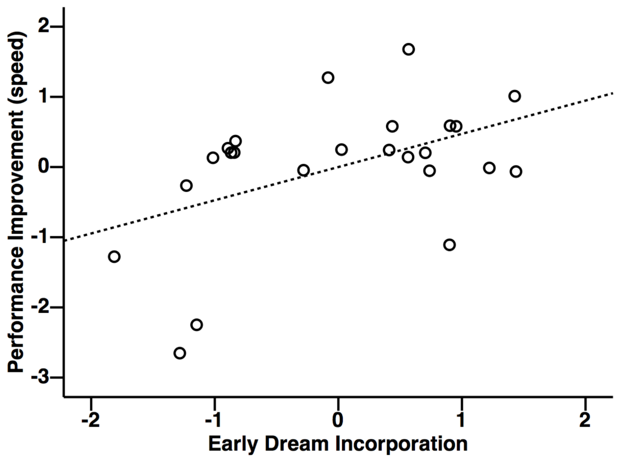

FIGURE 6 | Relationship between performance improvements for the tennis task and early dream incorporation. Performance improvements were correlated with early dream incorporation, but not late dream incorporation, or daydream incorporation. Units for *x* and *y* axes are displayed in standardized residuals (Z) scores.

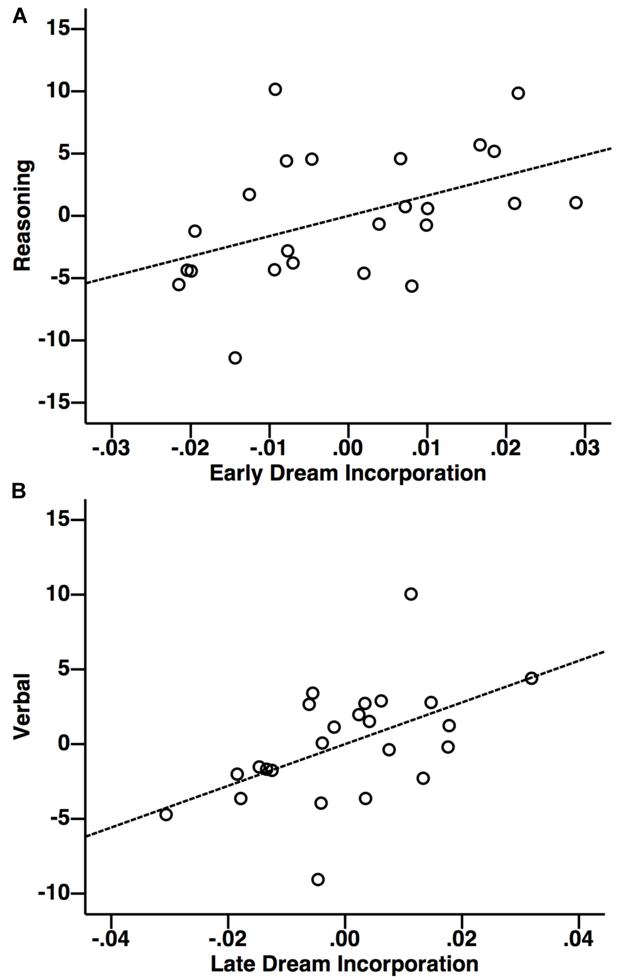

FIGURE 7 | Relationship (partial correlation) between dream incorporation and reasoning **(A)** and with verbal **(B)** abilities. Greater early dream incorporation was associated with higher reasoning ability (controlling for verbal ability and STM), whereas greater late dream incorporation was associated with higher Verbal ability (controlling for reasoning ability and STM). Units for *x* and *y* axes are displayed in standardized residuals (Z) scores.

[$F(2,21) = 3.60, r = 0.51, p = 0.045$]. In this model, inspection of the partial coefficients revealed that this relationship was significant for the tennis task (**Figure 6**: $r = 0.47$, $p = 0.023$), but not for the navigation task ($r = 0.08$, $p = 0.71$). By contrast, performance improvements did not relate to late dream incorporation [$F(2,21) = 1.68$, $r = 0.37$, $p = 0.21$] or daydream incorporation [$F(2,21) = 0.09$, $r = 0.12$, $p = 0.92$].

In order to follow-up whether initial performance on the tasks was correlated with dream incorporation, the exact same analysis strategy was conducted using performance scores during the first two trials of the training session. None of the analyses revealed any statistically significant effects (all $p > 0.90$). Thus, suggesting that learning-related improvements, but not inter-individual differences in initial skill for the task, were related to the extent of dream incorporation for early, but not late dreams or daydreams.

Step 2: Dream Incorporation and Cognitive Abilities

Multiple regression revealed that altogether Reasoning, Verbal, and STM accounted for a significant proportion of variability in early dream incorporation [**Figure 5**; $F(3,21) = 4.17$, $p = 0.019$]. Interestingly, in this model, inspection of the partial coefficients revealed that Reasoning (**Figure 7A**; $r = 0.41$, $t = 2.36$, $p = 0.029$), but not Verbal or STM significantly and uniquely accounted for variability in dream incorporation. Similarly, altogether Reasoning, Verbal, and STM accounted for a significant proportion of variability in late dream incorporation [**Figure 5**; $F(3,21) = 3.18$, $p = 0.046$). However, by contrast, inspection of the partial coefficients revealed that for late dream reports, Verbal (but not reasoning ability or STM) uniquely predicted late dream incorporation (**Figure 7B**; $r = 0.50$, $t = 2.69$, $p = 0.014$). Thus, suggesting a dissociation between cognitive abilities and early vs. late dream incorporation. In addition, there was no relationship between intellectual abilities and daydream incorporation [$F(3,21) = 1.70$, $p = 0.1$), suggesting that the relationship between cognitive abilities and incorporation may be specific to sleep and dreams.

Step 3: Cognitive Abilities and Performance Improvements

Multiple regression revealed that performance improvements were unrelated to cognitive abilities including Reasoning, Verbal, and STM (all $p > 0.26$). Given that Step 3 was not significant (**Figure 5**), according to Judd and Kenny (1981), James and Brett (1984), and Baron and Kenny (1986), this precludes the possibility that cognitive abilities mediate the relationship between performance improvements and dream incorporation, and thus Step 4 was not necessary to test for the nature or extent of the mediation (e.g., either total or partial mediation).

Finally, in order to follow-up whether initial performance on the tasks was correlated with cognitive abilities, the exact same analysis strategy was conducted using performance scores during the first two trials of the training session. Surprisingly, none of the analyses revealed any statistically significant effects (all $p > 0.33$).

DISCUSSION

Is there any rhyme or reason to the mental activity reflected in our dreams; and if so, what is the functional significance of these thoughts? Given the links between: (1) sleep and memory, (2) learning and dream incorporation, and (3) between sleep and cognitive abilities, we explored whether the richness of learning-related incorporation of novel daytime experiences into the content of our dreams was related to intellectual abilities. Similar to previous studies, it was found that improved performance, reflecting memory consolidation, was associated with the extent of dream incorporation into early but not late dream reports. Thus, suggesting that individuals who have richer dream incorporations, experience greater offline performance improvements. Surprisingly, the extent to which one improves on these tasks after sleep was unrelated to cognitive abilities, thereby precluding any mediation of the relationship between offline performance improvements and dream incorporation by inter-individual differences in cognitive abilities. In addition, inter-individual differences in the level of initial performance (first two trials of practice) at the training session did not relate to the extent of dream incorporation, or to inter-individual differences in cognitive abilities. Importantly, we identified a relationship between the extent of dream incorporation and reasoning abilities (but not verbal abilities or STM), and only for early dream reports. By contrast, verbal cognitive abilities were associated only with late dream reports. These effects appear to be specific to sleep, given that incorporation into daydreams was generally lower and unrelated to performance improvements, and also, unrelated to cognitive abilities. It is important to note that the association with cognitive abilities was investigated using dream incorporation of waking experiences, not dream frequency or dream content, *per se*. In the past, dream frequency and dream content were found to have only weak, inconsistent and disparate links to individual cognitive traits (Blagrove and Pace-schott, 2010). Taken together, these results suggest that individuals with greater performance improvements, more richly incorporate newly learned experiences into the content of their dreams, and that the extent of this dream incorporation was related to reasoning abilities. Thus, suggesting a trait-like relationship between the extent of the learning-related dream incorporation and cognitive abilities.

The idea that dreams may be linked to our cognitive capacities is not new (Foulkes, 1985; Domhoff, 2003, 2010). However, there is little empirical evidence supporting this relationship to date. The first scientific studies to suggest this link was in a series of longitudinal (Foulkes, 1982) and cross-sectional (Foulkes et al., 1990) studies in children exploring the relationship between REM dream content (e.g., dream frequency and narrative complexity) and cognitive capacities over the course of development in children age 5 to 15 years old. The only consistent predictor of dream frequency from the battery of cognitive aptitude tests (e.g., visuospatial, verbal, descriptive, and memory abilities), was the block design test of the WISC, which assesses visuospatial skills. Other studies also have shown that visual memory is associated with dream recall frequency (Cory et al., 1975; Butler and Watson, 1985; Schredl and Montasser, 1996a,b). Taken together, these studies suggest that dreaming is window into understanding how sleep relates to trait-like cognitive capacities. Surprisingly, to our knowledge, this is the first study in adults exploring the relationship between intellectual abilities and learning-related dream incorporation.

Not only have cognitive abilities been linked to dreams, they have also been linked to sleep-related memory consolidation. Specifically, Smith et al. (2004) found that individuals with high Intelligence Quotient (IQ) scores had greater learning-dependent changes in REMs during REM sleep. In addition, individuals with high Weschler Memory Scale scores had a greater declarative learning-related increase in sleep spindle activity, and benefitted more from sleep than individuals with lower scores (Schabus et al., 2006). However, Tucker and Fishbein (2009) found that IQ (as measured by the MAB-II) predicted better training and retest performance on declarative and procedural memory tasks, but did not correlate with overnight changes in performance. While the evidence remains sparse, together, these studies suggest that the features of REM and non-REM sleep, including REMs (Smith et al., 2004; Fogel et al., 2007a) and spindles (Schabus et al., 2006; Bódizs et al., 2008; Fogel and Smith, 2011; Geiger et al., 2011; Gruber et al., 2013; Hoedlmoser et al., 2014; Ujma et al., 2014; Fang et al., 2017), may serve as physiological indices of trait-like verbal and reasoning cognitive abilities, respectively. The results of the present study suggest that there may also be physiological correlates of reasoning abilities early (close to sleep onset) and for verbal abilities later in the sleep period during hypnagogic states. However, this possibility remains to be explored.

It is important to note that in the current investigation, while waking daydreams were collected, a separate wake control condition was not included, and thus, we cannot draw the conclusion that performance improvements were indeed "sleep-dependent," *per se*. However, this was not the focus of the current investigation. Nonetheless, the performance improvements from training to retest support the notion that learning occurred, and that similar to previous studies, memory consolidation did take place (re; there was no forgetting, or performance decrements). Moreover, given that the relationship between improved performance and the extent of incorporation was only observed during early dreams and not daydreams would suggest that sleep was an opportune time for memory processing to take place. However, it should be noted that early dream incorporation was related only to performance improvement in the tennis but not the spatial navigation condition. In addition, dream incorporation was correlated to performance improvements for early but not late dream incorporation. This pattern of results warrants replication and further investigation in order to draw any meaningful conclusions or identify any important functional dissociations. Finally, while many of the *p*-values from the main statistical analyses were statistically significant, they did not greatly exceed $p < 0.05$. However, we did have strong *a priori* hypotheses, which flowed from the previous literature, and tested these hypotheses using a systematic approach to look for possible mediation of the three main sets of variables (dream incorporation, cognitive abilities, and memory performance). This was done using multiple regression, following the very well established procedures proposed by Judd and Kenny (1981), James and Brett (1984), and Baron and Kenny (1986). Importantly, it should be noted that the analysis procedure employed here has relatively low power, and thus, detection of statistical significance may be underestimated. Indeed, upon inspection of the partial coefficients, statistically significant effect sizes ranged from 0.41 to 0.48, which according to Cohen's standards (Cohen, 1988) are considered "medium" effect sizes (>0.3). Moreover, Kenny points out that because these are indirect effects, and the product of two effects, they actually underestimate effect sizes, arguing instead that Cohen's recommendations should be squared. If so, our results should all be considered to have "large" effect sizes. In other words, in contrast to previous studies, our main findings explain over 40% of the variability in our variables of interest (e.g., dream incorporation).

The capacity for reasoning, as assessed in the present study by the CBS Trials test battery, tap into aspects of "fluid intelligence" (adapted from items from the Cattell Culture Fair Intelligence Test), which most closely relate to the WAIS (and MAB-II) Performance IQ, and the Raven's Advanced Progressive Matrices. Fluid intelligence has been said to represent the innate (i.e., constitutionally and biologically endowed) intellectual potential that gives rise to, but is distinct from crystalized intelligence, which develops through learning and experience (Boyle, 1988). It is considered the capacity to identify complex patterns and relationships, and the capacity to employ logic to solve novel problems. The relationship between reasoning abilities and early dream incorporation may reflect individual differences in how information is processed during sleep. The nature and the extent of this processing may depend on our reasoning abilities. When new information is learned, sleep is involved in the reactivation (Peigneux et al., 2003, 2006; Bergmann et al., 2011; Antony et al., 2012; Oudiette and Paller, 2013; Oudiette et al., 2013; Schönauer et al., 2014; Fogel et al., 2017), and even replaying (Skaggs and McNaughton, 1996; Louie and Wilson, 2001; Lansink et al., 2009) of newly learned experiences. This memory reprocessing is thought to be reflected in the content of our dreams as incorporations of waking novel, immersive or impactful experiences (Stickgold et al., 2000; Wamsley et al., 2010a,b; Kusse et al., 2012; Wamsley, 2014). These incorporations are not 1:1 representations of past experiences, rather, they tend to be intermingled with other seemingly unrelated content. This might reflect the process of integrating and transforming this new information into existing memory representations. Moreover, sleep is involved in facilitating the transformation of unconscious knowledge into conscious knowledge and problem solving (Wagner et al., 2004; Darsaud et al., 2011; Verleger et al., 2013; Spiers and Bendor, 2014). Here, the present study suggests that the extent of this processing might depend on reasoning abilities; the capacity to solve novel problems through the use of logic.

Given that indirect incorporations tend to occur later in the sleep period (Wamsley et al., 2010a) and that later dreams contain more indirect than direct incorporations (Wamsley et al., 2010a), it is possible that detecting a relationship with intellectual abilities is more difficult during late dreams due to the sparsity and disparate semantic links to waking experiences. This is, however, not necessarily supported by the present results given that Verbal abilities were significantly correlated with late dream incorporation. One parsimonious and interesting interpretation of this result is that individuals with better Verbal cognitive abilities are able to access, recall and articulate these more disparate dream incorporations more robustly. On the other hand, these individuals may be able to more richly recall dream content in general, and thus increase the probability of reporting related concepts. This may also explain why a difference in the absolute extent of incorporation between early and late dream reports was not observed. However, this interpretation remains speculative, and may require further study. There is, however, evidence to support the notion that high vs. low dream recallers have longer awakenings in response to auditory stimuli during sleep, regardless of sleep stage (Vallat et al., 2017), and greater brain reactivity regardless of sleep or wake (Eichenlaub et al., 2014). Thus, suggesting that high dream recallers likely process information to a greater extent than low dream recallers during sleep, and are more easily aroused. This may partly explain inter-individual variations in dream recall. Together, these results help to elucidate the relationship between verbal abilities and late dream incorporation – when dream incorporation is less directly semantically related, and possibly more difficult to recall and articulate. Future studies could investigate the neural correlates of the relationship between dream incorporation and cognitive abilities. Moreover, given the specific focus of the current study on non-REM dream content, we cannot infer, or directly compare these findings to REM dream-related phenomena. Interestingly, however, learning-related dream incorporation into REM dreams is strongest on the night after and from 5–7 nights after learning, reflecting "day residue" and "dream-lag" effects, respectively (Nielsen et al., 2004; van Rijn et al., 2015). It would be important for future studies to apply the approach developed here to study the relationship between cognitive abilities and learning-related incorporation into REM dream content, when dream incorporation is maximal.

The relationship between cognitive abilities and dream incorporation appeared to be specific to sleep and also specifically related to the experimental learning conditions. There was no relationship between behavioral improvement and incorporation into daydream reports, nor any relationship between daydream incorporation and cognitive abilities. Thus suggesting that the relationship between dream incorporation and cognitive abilities are specific to sleep, and not mental content during wakefulness interspersed between sleep episodes, i.e., "daydreaming." Moreover, within condition semantic similarity was higher than between conditions.

Thus, the overall pattern of results was specific to sleep and to the unique incorporation of the learning-related experience.

A major challenge to the study of dreams is that they are typically analyzed by rating and ranking the content of verbal dream reports along various dimensions by judges (Hall and Van De Castle, 1966), or by the dreamers themselves. With the exception of a few recent studies (Amini et al., 2011; Horikawa et al., 2013; Wong et al., 2016), the majority of dream research has been limited to the study of subjectively scored and interpreted dream reports. However, recent advances in language processing and machine learning techniques (Amini et al., 2011; Horikawa et al., 2013; Wong et al., 2016) have made the objective analysis of dream reports possible. The current study employed WordNet, a manually curated publicly available lexical database of the English language that can be used to derive the high-order meaning of words from a corpus of text, as well as the semantic distance between the higher-order senses of words with another corpus of text. In this way, we were able to objectively derive the higher-order semantic meaning of the wake reports generated immediately after mental rehearsal of the previously learned task. We could then compute the semantic distance between these concepts with subsequent dream reports obtained from post-learning sleep. This method is advantageous in that it is not necessary for a human scorer to interpret the meaning of the words in the reports, or to infer how direct incorporations were. Moreover, this approach avoids the possibility that individuals with higher cognitive abilities may be able to better generate confabulations about waking life into dreams (Henley-Einion and Blagrove, 2014). This provides a novel method to objectively quantify dream incorporation for future studies.

Ultimately, this line of investigation leads to the question: can dreaming actively contribute to intellectual functioning and cognitive abilities? Unfortunately, despite the use of mediation analysis, the direction of causation cannot be inferred from the results of this study, as these relationships are inherently correlational. However, the present study suggests that when something new is learned and this new learning is incorporated into dreams, the extent to which this occurs is associated with improved performance, and also with the capacity for reasoning. This is consistent with the proposition that cognitive abilities support dream formation (De Koninck, 2012) and that dreaming is a period where the brain, being unfettered by the constraints of information processing during waking (Klinger, 1978), is ideal for novel and creative thought (Foulkes, 1985) that may support novel solutions to new problems (Barrett, 1993) and creative thinking (Bone and Corlett, 1968; Fitch and Armitage, 1989; Streich, 2009). To the best of our knowledge, there are no studies to date that have investigated whether dream incorporation is related to cognitive abilities. One study, however, by De Koninck et al. (1989) found that during a period of intensive second language learning, those who progressed well, experienced incorporations into dreams earlier and had more verbal communication in their dreams during the language training than those who made little progress. Taken together, these studies are consistent with the conclusion that there is a relationship between learning proficiency and cognitive abilities during dreaming in humans.

In summary, here we identified, for the first time, that the extent of dream incorporation of a novel and immersive period of learning experience was related to cognitive abilities. These reflect the ability to apply logic and reasoning to solve problems (or, what is also known as Performance IQ, or fluid intelligence). The relationship between dream incorporation and reasoning abilities was strongest in early dream reports, when incorporations have been found to be more direct (Wamsley et al., 2010a), and when offline improvements in performance were related to the extent of the dream incorporation. On the other hand, there was no relationship with early dream reports to other cognitive abilities that reflect the use of existing knowledge (also known as Verbal IQ or crystalized intelligence), or to STM. However, the extent of dream incorporation was related to verbal abilities for dream reports collected later in the sleep episode when incorporations have been found to be less direct (Wamsley et al., 2010a). This finding suggests that individuals with greater verbal abilities are able to better recall or articulate weak incorporations.

These results provide evidence that the extent to which we incorporate newly learned material into our dreams is related to our cognitive abilities, in particular, our capacity for reasoning, problem solving and the use of logic. On the other hand, while verbal abilities are related to dream incorporation, it is at a time where incorporations are disparate, and when dream incorporation is unrelated to memory consolidation. Importantly, this study provides evidence that dream production is related to our cognitive strengths and weaknesses.

AUTHOR CONTRIBUTIONS

LR and VS carried out the study. SF and AO were involved in planning and supervised the work. LR and SF processed the data, performed the analysis, drafted the manuscript, and designed the figures. JDK aided in interpreting the results and worked on the manuscript. All authors discussed the results and commented on the manuscript.

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Dreams of Teeth Falling Out: An Empirical Investigation of Physiological and Psychological Correlates

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Teeth dreams (TD), i.e., dreams of teeth falling out or rotting, are one of the most common and universal typical dream themes, yet their source remains unknown and they have rarely been studied empirically. They are especially enigmatic as they do not readily fall under the rubric of the "continuity hypothesis", i.e., dreams of current and salient waking-life experiences. The aim of the present study was to explore two possible hypotheses for the origin of TD; specifically, TD as incorporation of dental irritation into dreaming, and TD as a symbolic manifestation of psychological distress. Dream themes, dental irritation, psychological distress, and sleep quality were assessed among 210 undergraduates. TD were related to dental irritation (specifically, tension sensations in the teeth, gums, or jaws upon awakening), whereas other dream types were not. Conversely, TD were unrelated to psychological distress, whereas other dream types were (specifically, dreams of being smothered and dreams of falling). This disparity in the correlates of TD existed despite a small but significant relationship between psychological distress and dental irritation. Albeit preliminary, the present findings support the dental irritation hypothesis and do not support the symbolic hypothesis regarding the origins of TD. Research on TD portrays one path through which the mind may distort somatosensory stimuli and incorporate them into dreams as a vivid and emotionally salient image; these preliminary findings highlight the potential of studying TD in order to broaden our understanding of the cognitive mechanisms governing dream production.

Keywords: typical dreams, sleep bruxism, teeth grinding, continuity hypothesis, psychopathology

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INTRODUCTION

Dreams of teeth falling out, losing one's teeth, or teeth breaking or rotting, constitute one of the most prevalent typical dream themes. For example, in one study, 39.0% of respondents reported that they had experienced teeth dreams (TD) at least once, 16.2% reported that their TD were recurrent, and 8.2% reported that their TD were regular (Yu, 2012). TD are so prevalent that they have even received portrayals in popular media, such as the Walt Disney movie "Inside Out" (Rivera and Docter, 2015), in which they were depicted as a manifestation of distress (a reasonable hypothesis which we will discuss further below). The commonness of TD is somewhat inexplicable, as it is incompatible with the "continuity hypothesis", according to which, we dream of our waking concerns and waking life-experiences (e.g., Domhoff, 1996). In other words, it is difficult to explain why so many people dream, sometimes regularly, of the experience of teeth falling out, breaking, or rotting, experiences which are not particularly common in waking life for adults. Understanding this disparity may be important for understanding the mechanisms governing dream production. Nevertheless, this topic has hardly received empirical attention, even within the narrow field of dream research.

Because TD are so common and universal, there have been several attempts to provide interpretations for them. Perhaps the earliest documented interpretation was given in Ancient Greece by Artemidorus, who meticulously divided the oral cavity to several components (e.g., molars, incisors, right and left side of the mouth) and gave each part a specific meaning. For example, he related losing teeth in a dream to the payment of debts (Coolidge, 2006). Soon after, in the Jewish Talmud, TD were construed as a prophecy for the impending death of a family member (Gutheil, 1951). The connection between TD and death was a common belief for many years, which Freud (1900) reacted to with irony, suggesting instead that TD represent sexual elements including masturbation and castration. Notably, however, Freud also referred to an assumption that had already existed in his time, according to which, TD were related to dental stimuli (in his view, this simple explanation was probably true, yet absolutely insufficient). Other interpretations of TD included Jung's reported notion that TD in women represented childbirth (see Freud, 1900), as well as a more recent interpretation of TD as the fear of growing older (Schneck, 1967).

More recently, Yu (2012) found a correlation of TD with a dream content scale assessing somatosensory and motor experiences in dreams, such as falling, being chased, or flying (see Yu, 2010), and this correlation was stronger than that of TD with other dream content scales. Yu (2012, 2016) interpreted this scale as "sensorimotor excitement" and hypothesized, as Freud and his contemporaries did, that TD may be related to dental stimulation. Moreover, Revonsuo (2000) specifically hypothesized that TD are triggered by episodes of sleep bruxism, as the sensations elicited in the mouth are incorporated into the dream. This idea is in accordance with findings from modern sleep research on "incorporation", specifically, studies on the effect of somatosensory stimuli on dream content using experimental manipulation (e.g., Dement and Wolpert, 1958; Nielsen, 1993). This line of research, showing that at times incorporation is possible, suggests that the origin of some dreams is most likely physiological rather than a direct or symbolic portrayal of psychological concerns. However, to the best of our knowledge, the hypothesis about the link between TD and dental irritation has never been empirically tested.

Dental irritation, stimulation, or tension during sleep may be considered as one of the indicators of teeth grinding or clenching according to the ICSD-2 diagnostic criteria for sleep-related bruxism (American Academy of Sleep Medicine, 2005). Dental irritation during the night is very common; it has been reported that 85–90% of the population grind their teeth at some point in their lives (ICSD; American Sleep Disorders Association, 1990). The prevalence of sleep bruxism tends to decrease with age and stands at 8.6% in the general population with no gender differences noted (Khoury et al., 2016). Nevertheless, it is worth noting that this may be an underestimation because people are often not aware of their habit to grit their teeth and/or lack a bed partner to draw their attention to the gnashing noise (e.g., Lavigne and Montplaisir, 1994; Kampe et al., 1997; Bader and Lavigne, 2000).

Kato and Lavigne (2010) listed clinical features for evaluation and diagnosis of sleep bruxism which include: self-report from sleep partners or parents who complain about grinding sounds, various conditions reported by bruxers upon awakening (e.g., jaw muscle discomfort, fatigue or stiffness, and tooth hypersensitivity), clinical observations (e.g., visual inspection), and miscellaneous (e.g., dental restoration failure or fracture). The possibility that many people grind their teeth, although they are not aware of it, may be the explanation for the commonness of TD, if they are in fact related to dental irritation. We hypothesize that TD may be related to such irritation, manifested in a sense of tenderness or tension in the teeth, gums or jaws upon awakening. The first goal of the present study was to examine in an exploratory manner whether there will be a significant correlation between TD and dental tension upon awakening. To explore the specificity of this relation (and its superiority over other correlations which may be influenced by self-report bias), we will also explore: (1) the correlation between TD and other types of sleep disturbances, and (2) the correlation between dental tension upon awakening and other typical dream themes.

In addition, in recent years it has been reported that an array of unusual dreams, including dreams of flying or falling, vivid dreams, recurring dreams, and dreams of dying, are components of a construct labeled "sleep experiences" (Watson, 2001). This construct is closely related to psychological symptoms and stress (Soffer-Dudek, 2017). TD have also been directly related to psychopathology (Coolidge and Bracken, 1984). This gives rise to an alternative, or supplementary, hypothesis, suggesting that TD may be related to psychological distress. This hypothesis may perhaps be viewed as the psychological/symbolical, rather than the physiological, interpretation of TD. Possibly, both hypotheses may be correct, especially since grinding teeth has been in itself perceived as a physical manifestation of stress and anxiety (Manfredini et al., 2005).

MATERIALS AND METHODS

Participants and Procedure

This investigation was part of a larger study on dissociation and related constructs (Soffer-Dudek, 2018). In that study, data were collected from 303 undergraduate students in exchange for either course credit or reimbursement. Unfortunately, the two dental irritation items, central to this study (teeth grinding and teeth tension), were mistakenly omitted from the battery of questionnaires originally administered. Hence, they were administered 3 weeks later to those participants who agreed to complete them, which were $N = 217$ (72% of the sample). Independent samples t-tests demonstrated no significant differences between this subset of the sample and the rest of the participants on all study variables, including age, dream themes, psychopathology, sleep variables, and a chi-square test suggested that they were also not different in gender.

Missing data on study variables for the 217 participants were negligible (between 0 and 2.3% for any variable), and thus we did not implement any method for missing data completion; When missing data are lesser than 5%, any method for dealing with them would probably lead to the same results (Tabachnick and Fidell, 2007). However, we used the bootstrapping method (as detailed below), which automatically employs listwise deletion. Thus, our final sample for analyses consisted of $n = 210$ with full data (76.7% females, Mage = 23.4, $SD = 1.43$, and range: 18–28).

The participants signed up for a study labeled "Dissociation, attention, vulnerability, and resilience" via the institutional psychological experiments system. Through this system, they received a link to online survey software (Qualtrics, Provo, and UT) presenting the questionnaires. Ethical considerations of this study were approved beforehand by Ben-Gurion University's institutional review board. After signing the electronic consent form, the participants completed the questionnaires in one of two possible fixed orders, which were counterbalanced between two randomly selected subsets of participants. Participants were instructed to respond to the questions as honestly as possible and to contact the researchers if they encounter any difficulties or concerns. The participants were subsequently debriefed regarding the purposes of the study. The procedure was completed in approximately 50 min.

Measures

Dream Themes

The Dream Motif Scale (DMS; Yu, 2012) was designed to assess the lifetime frequency of experiencing particular dream content on a 5-point response scale (0 = never, 4 = once a month or more often). The full DMS consists of 100 dream themes, generating 14 subscales, each measuring a hypothesized "dream predisposition". We used four items that were found by Yu (2012) to be highly correlated with the "Sensorimotor Excitement Scale": item 12 ("falling"), item 18 ("your teeth falling out, losing your teeth, or your teeth rotting"), item 30 ("being unable to find, or embarrassed about using, a toilet"), and item 39 ("being smothered, and unable to breathe"). The DMS has excellent psychometric properties; the alpha reliability coefficients for all of its scales were reported to exceed the conventional level of 0.7. The structures of the DMS dimensions have been validated by item analyses, exploratory factor analyses, and confirmatory factor analyses.

Psychological Distress

The Brief symptom inventory (BSI; Derogatis and Melisaratos, 1983) is a 53-item scale assessing a wide range of self-reported psychological symptoms, including somatization, obsessive-compulsive symptoms, interpersonal sensitivity, anxiety, depression, hostility, phobic anxiety, paranoid ideation, and psychoticism, pertaining to the past month. It is useful for measuring general psychological distress. Participants estimated the frequency of their distress experiences in the past month on a 5-point scale (0 = not at all, and 4 = extremely). The authors document high test-retest and internal consistency reliabilities, and good evidence of convergent, discriminant and construct validity. A global BSI score was computed by averaging the 53 items, and subscale scores were computed by averaging the relevant items belonging to each scale. Cronbach's alpha in the present study was 0.96 for the total score.

Dental Irritation

The two questions used in the present study to evaluate self-reported sleep bruxism were constructed based on: (1) the respondent's awareness to grinding (item #1- teeth grinding: "I tend to grind my teeth while I am asleep") and on: (2) vague sensations grinders may feel upon awakening, even if they are unaware of grinding, mentioned by the American Academy of Sleep Medicine (2005) as a diagnostic criterion of Sleep Bruxism (item #2- teeth tension: "Upon awakening I experience a sense of tenderness or tension in my teeth, gums or jaws"). Participants estimated the frequency of their dental irritation experiences pertaining to the past month, on a 6-point scale (0 = never or rarely; 1 = has happened a few times, but not in the last month; 2 = once in the last month; 3 = twice or three times in the last month; 4 = once in the last week; and 5 = more than once in the last week). The two items were significantly correlated [$r = 0.63$ (0.51, 0.72), $p < 0.001$], however, we used them separately in order to explore correlations when individuals are unaware of their grinding (represented by item #2). Single self-report items have been used to assess sleep bruxism in additional studies (Ohayon et al., 2001; Winocur et al., 2011; Shokry et al., 2016).

Sleep

Sleep quality was measured with the Pittsburgh Sleep Quality Index (PSQI: Buysse et al., 1989). The PSQI measures sleep quality of the past month. It consists of 19 items, summed up into seven components and a global score. Components include subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. Authors report acceptable measures of reliability and validity for this measure. We applied the Hebrew version of the PSQI which has been validated in Shochat et al. (2007). Cronbach's alpha for the seven components in this study was 0.68. In this study, we used the global score (based on all 7 factors and representing poor sleep quality), as well as a single component which was of special interest to us: the sleep disturbances component. The latter was calculated as the mean score of ten sleep disturbances depicted in the questionnaire (e.g., cannot breathe comfortably, feel too hot, and had bad dreams). We labeled this scale general sleep disturbances, as opposed to dental disturbances, which are not included in the PSQI. We aimed to use this component in order to explore specificity of dental irritation as opposed to other types of disturbances to sleep. Notably, high scores on either of these variables (the global score or the general sleep disturbances component) indicate poor sleep quality.

Data Analysis

Our aim in this study was to explore possible associations between variables, in a preliminary, cross-sectional design. All analyses were conducted with SPSS software (version 23). Because some of our variables (specifically, typical dream types and dental irritation items) were based on single items (with Likert-type response scales), we used Spearman rank-order correlation coefficients to explore relationships between the variables. We wish to note, however, that results were not significantly different when using Pearson zero-order correlation coefficients, or when using partial correlations controlling for gender[1]. Because the distributions of teeth grinding, teeth tension, TD, dreams of being smothered, toilet dreams, psychological distress and poor sleep quality were all positively skewed, we employed bootstrapping in order to test for significance without the need to assume normal distributions. The correlations were computed based on 1,000 bootstrapped resamples, and the 95% confidence intervals were computed using the bias-corrected and accelerated method.

RESULTS

Table 1 presents means, standard deviations, and rank-order correlations for all study variables, specifically: the two dental irritation variables (i.e., teeth grinding and teeth tension), four typical dream themes (including TD, as well as falling, being smothered, and searching for a toilet), psychological distress, general sleep disturbances and poor sleep quality. As can be seen in the table, TD were positively associated with the teeth tension item, with a small-to-medium effect size [$r = 0.21$ (0.07, 0.33), $p < 0.005$], but were not associated with the item directly assessing teeth grinding [$r = 0.06$ (−0.07, 0.20), ns]. In fact, the latter item was not significantly associated with any of the other variables except for teeth tension (not even sleep quality or general sleep disturbances). Importantly, all three non-teeth typical dream themes were unrelated to dental irritation items, supporting the specificity of the TD-dental irritation relation. The hypothesis according to which psychological distress will be related to TD was not supported[2] [$r = 0.02$ (−0.11, 0.16), ns], although psychological distress was related to teeth tension [$r = 0.14$ (−0.01, 0.28), $p < 0.05$]. Despite the statistical significance of the latter correlation, this association should be interpreted with caution, as the bootstrapped 95% confidence interval includes zero. Finally, TD were unrelated to sleep disturbances or sleep quality. The main results of the study are depicted in **Figure 1**.

Other notable findings from these data were associations between dreams of being smothered (or unable to breathe) with psychological distress, general sleep disturbances, and poor sleep quality. Dreams of searching for a toilet were weakly associated with general sleep disturbances, and dreams of falling were weakly related to psychological distress.

DISCUSSION

The present study aimed to explore whether TD would be related to a physiological stimulus, specifically, dental irritation, or to a psychological or symbolic possible origin, specifically, psychological distress, or to both. Our first hypothesis, according to which TD would be significantly associated with dental irritation, was supported, with a small to moderate effect size. However, this relation reached statistical significance only for teeth tension, i.e., the item that indirectly assesses possible sleep bruxism of which the individual may be unaware, rather than the direct-assessment item pertaining to teeth-grinding. Although this may stem from the dearth of measures used in this study to assess bruxism, it may also represent support for the notion that most people may be unaware of their sleep bruxism yet may be aware of dental stimulation following the sensations in the organs located around and in the oral cavity after awakening (Rompré et al., 2007). We believe that the lack of effect with the direct-assessment item was brought about because many are unaware of grinding, and thus the variable probably had less variance in our sample, hindering the ability to identify relationships with it[3]. To the best of our knowledge, this is the first study to empirically demonstrate preliminary findings toward confirming the association between TD and dental irritation. It suggests one possible path through which the mind may distort somatosensory stimuli and incorporate them into dreams as a vivid and emotionally salient image (see Nielsen, 1993 for additional examples of such distortion)[4].

In light of the small-to-medium magnitude of the relation, it is essential to examine the specificity of this association. Indeed, the results identified specificity in both directions. First, teeth tension was the only non-dream item correlated with TD, whereas general sleep disturbances, overall sleep quality, and psychopathology were unrelated to TD. Second, dental irritation was unrelated to other typical dream themes. To the extent that such specific results will replicate in future studies, this specificity supports the interpretation that TD follow dental irritation, or more broadly, that somatosensory stimulation influences and penetrates the content of dreams, albeit, taking on a vivid, emotional, and distorted, form (Nielsen, 1993). Importantly, however, causality may not be ascertained from our cross-sectional design. For example, it is also possible that TD bring about teeth clenching, which may cause tension upon awakening. Future research should employ a longitudinal diary design or induced awakenings in the sleep laboratory in order to establish chronological directionality.

[1] We hypothesized that gender may pose a confound, because women recall more dreams (Schredl and Reinhard, 2008), and report more psychological distress (Al-Issa, 1982), especially internalizing, rather than externalizing, mental health issues (Eaton et al., 2012). Thus, we attempted to control for gender in all analyses using partial correlations. Results remained unchanged.

[2] Due to the non-significant correlation between TD and the BSI total score, we also explored BSI subscales to see if there were any specific symptom scales that would correlate with TD. However, none of the subscales correlated significantly with TD. Effect sizes ranged from $r = -0.02$ to $r = 0.12$.

[3] Indeed, looking at the distribution of the teeth grinding variable, we noticed that it was very peaked, with high kurtosis (>2), whereas the teeth tension variable had normal kurtosis (<1), implying more variance in our sample.

[4] Interestingly, prevalence rates presented in the Introduction section for TD (8.2%) and for Bruxism (8.6%) are very similar; possibly, this similarity stems from their connection. We thank the reviewer who brought this to our attention.

TABLE 1 | Means, standard deviations, and rank-order correlation coefficients of teeth dreams (TD), falling dreams, dreams of being smothered, toilet dreams, psychological distress, teeth grinding, teeth tension, poor sleep quality, and general sleep disturbances.

	1	2	3	4	5	6	7	8	9
(1) Teeth dreams (TD)	1.00								
(2) Falling dreams	0.34** [0.22, 0.43]	1.00							
(3) Dreams of being smothered	0.20** [0.05, 0.34]	0.27** [0.14, 0.38]	1.00						
(4) Toilet dreams	0.32** [0.18, 0.45]	0.22** [0.10, 0.33]	0.26** [0.11, 0.40]	1.00					
(5) Psychological distress	0.02 [−0.11, 0.16]	0.13* [0.02, 0.27]	0.27** [0.12, 0.39]	0.00 [−0.13, 0.14]	1.00				
(6) Teeth grinding	0.06 [−0.07, 0.20]	0.05 [−0.09, 0.18]	−0.01 [−0.15, 0.12]	0.02 [−0.11, 0.17]	0.02 [−0.13, 0.17]	1.00			
(7) Teeth tension	0.21** [0.07, 0.33]	0.08 [−0.06, 0.20]	0.11 [0.00, 0.24]	0.02 [−0.11, 0.16]	0.14* [−0.01, 0.28]	0.63** [0.51, 0.72]	1.00		
(8) Poor sleep quality	0.04 [−0.10, 0.17]	0.09 [−0.02, 0.22]	0.19** [0.07, 0.31]	0.05 [−0.08, 0.18]	0.50** [0.39, 0.61]	0.06 [−0.07, 0.20]	0.08 [−0.07, 0.23]	1.00	
(9) General sleep disturbances	0.09 [−0.05, 0.23]	0.13 [0.00, 0.26]	0.27** [0.13, 0.39]	0.14* [0.00, 0.26]	0.49** [0.38, 0.59]	−0.01 [−0.16, 0.13]	0.06 [−0.08, 0.21]	0.66** [0.59, 0.72]	1.00
M	0.54	1.65	0.36	0.47	0.71	0.84	1.04	0.68	5.36
SD	1.02	1.2	0.75	0.85	0.5	1.46	1.51	0.45	2.84

**p < 0.05, **p < 0.01. In brackets are the 95% bootstrapped confidence intervals, using 1,000 resamples, calculated with the bias-corrected and accelerated method and rounded down to two decimals.*

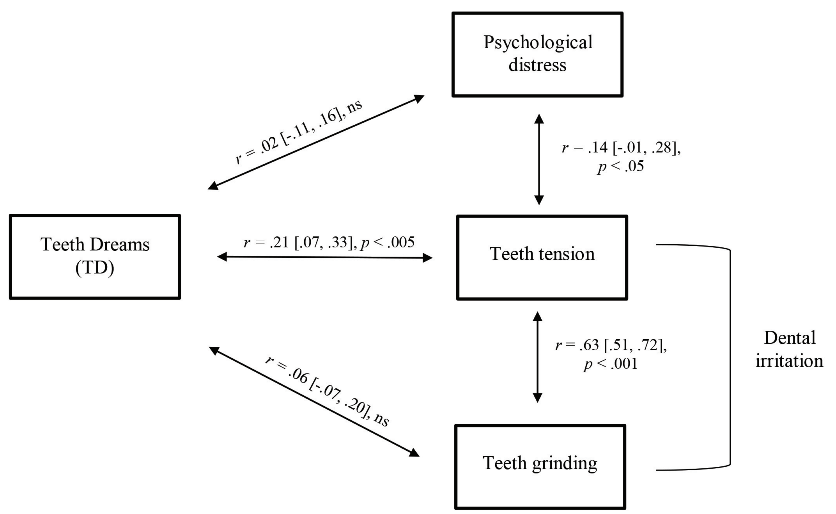

FIGURE 1 | A figure depicting the main results: rank-order correlation coefficients linking teeth dreams (TD) with dental irritation (teeth tension and teeth grinding) and psychological distress.

Interestingly, the two dental stimulation items were unrelated to sleep quality or to general sleep disturbances. These results are consistent with Veldi et al. (2005) who found that sleep quality was unrelated to a number of sleep problems, including sleep bruxism. However, they do not appear to corroborate with Castroflorio et al. (2017) who showed a strong association between sleep bruxism and other sleep disturbances, especially snoring. Due to the preliminary nature of our study, further research is needed in order to gain a deeper understanding of the relation between bruxism and sleep quality, perhaps measuring these constructs as states rather than traits.

Somewhat surprisingly, in contrast to a previous finding (Coolidge and Bracken, 1984), at least in our preliminary study, TD were not associated with psychological distress at all, nor were there any correlations with specific psychological symptom subscales. This is in spite of the fact that psychological distress was indeed (weakly) related to sensitivity or tension in teeth, supporting the claim that anxiety and stress are related to teeth grinding (Ohayon et al., 2001; Manfredini et al., 2005;

Kato and Lavigne, 2010). Again, to the extent that these preliminary findings will be replicated in future studies, this negates the potential confounding effect of psychological distress as an explanation for the relation of TD with teeth tension. However, it is important to consider that perhaps the BSI or its subscales are not the ideal measures to explore the hypothesized symbolic association between TD and psychological distress. For example, perhaps TD are related to some specific type of distress (e.g., fear of eating, and fear of speaking) which would be better assessed with specific symptom scales. This should be explored in future studies.

Importantly, we considered the possibility that our procedural technicality described in the Method section may have affected the magnitude of relations found; specifically, self-report measures administered concurrently may have inflated correlations due to context effects (Podsakoff et al., 2003). However, this means that context effects should have inflated the relation of TD with psychological distress (as they were administered concurrently), as compared to the relation of TD with dental irritation (as they were administered 3 weeks apart). Hence, the procedural mistake could have been an alternative explanation only to the extent that we would have found a stronger relation of TD with psychological distress than with dental irritation, but this was not the case; despite the possible context effect, we found that TD were related to dental irritation and were unrelated to psychopathology. Thus, our findings remain valid. Moreover, it is possible that a concurrent investigation would have resulted in a larger magnitude for the TD-dental irritation relationship.

Finally, another noteworthy finding which emerged in this study was an association of dreams of being smothered with both general sleep disturbances and with psychological distress. It seems that dreams of being smothered may have both somatic and psychological origins. On one hand, participants suffering from sleep-related respiratory pauses reported such dreams more often than controls (Yu and Thompson, 2016). On the other hand, MacFarlane and Wilson (2006) found that patients who report having breathing problems during waking dream of sensations of choking more often than patients with a sleep-related breathing disorder. This finding is in accordance with the continuity hypothesis and the idea that people are likely to dream about waking concerns and stressors (Schredl et al., 1998). Thus, it is possible that anxiety concerning suffocation may be one explanation for the correlation we found between psychological distress and dreams of being smothered. Furthermore, dreams of being smothered are reminiscent of a common phenomenon whereby individuals experience sleep paralysis while hallucinating that an evil presence (e.g., a demon or a spirit) sits on their chest and smothers them, with accompanying sensations of suffocation (Cheyne, 2003). Indeed, sleep paralysis is related to psychopathology (Sharpless and Barber, 2011). Moreover, sleep paralysis is an example of a sleep phenomenon which is influenced both by psychological factors (e.g., distress and social anxiety) as well as by physical sensations (e.g., shallow breathing, and body paralysis) (Solomonova, 2018). This phenomenon may suggest another pathway through which the sensation of suffocating during sleep may be connected to various types of psychopathology. Future work should focus on understanding and expanding the investigation of the origin of dreams of being smothered.

The current study has several limitations. First, our sample consisted of high-functioning college students and was biased toward women, which may restrict generalization to other populations. Second, in the current study we relied on single, self-report items to assess dental irritation. Although a considerable number of studies also used a method of single items to estimate bruxism (e.g., Ahlberg et al., 2003; Shokry et al., 2016), this may pose a threat to the validity and the reliability of the measure. Moreover, assessing sleep bruxism via self-report measures can yield inaccurate results; on the one hand, Bader and Lavigne (2000) stated that people are often not aware of having sleep bruxism and thus it may lead to an underestimation of the prevalence; yet, on the other hand, Maluly et al. (2013) found that self-reports may overestimate the diagnosis of sleep bruxism, despite the existing overlap between the objective and the subjective measures. Hence, future studies on the link between TD and dental irritation should examine sleep bruxism with a validated scale or with more objective measures, such as polysomnography (for example, see: Lavigne et al., 1996) and clinician observation. Third, the dearth of measures of both TD and physical complaints in this study limits our ability to identify the extent to which this relation is specific. In other words, while there was one correlation between TD and dental irritation, with a modest effect size, we did not assess other physical complaints that could further bolster or generalize this finding, or increase the percentage of explained variance; it is possible that TD are related to a number of aches and pains, and symbolize physical pain more generally as opposed to specifically being associated with dental irritation. Conversely, future studies may bolster the specificity of these findings by assessing additional types of teeth complaints, such as gum soreness, chronic toothaches, tooth bridges, gingivitis, or sensitive teeth. There may also be a possible relation between waking bruxism and TD. Fourth, as mentioned above, self-reported sleep bruxism was assessed approximately 3 weeks after the rest of the variables, which may be one of the reasons for the modest magnitude of correlation found between TD and dental irritation. The assessment after 3 weeks also resulted in a smaller sample for the study. Future studies should rely on larger and more diverse samples. Notably, however, this also may be viewed as a strength, as the main findings cannot be alternatively explained by context effects, because same-context variables (psychological distress, and sleep quality) were unrelated to TD, whereas a different-context variable (dental stimulation) was. Fifth, psychological distress, sleep quality, and dental irritation were assessed pertaining to the past month, while dream themes were assessed as a lifetime experience, in accordance with the original response scales of each of these questionnaires. Future studies should assess TD in a given time frame rather than assessing a life-time prevalence. Future studies will also benefit from assessing the constructs with a daily-diary design, rather than as retrospective traits. Notably, given the fact that psychological distress and dental irritation may both be transitory, it is likely that the use of different time frames (i.e., the assessment of dental irritation 3 weeks later) led to a reduction of the effect size between dental irritation and TD. Nevertheless, these limitations do not constitute an alternative explanation for our results, according to which, dental irritation was associated with TD whereas psychological distress was not. Another limitation of the present study is that we did not correct the alpha-level for multiple tests (although the Bonferroni correction is not suitable with interdependent measures, perhaps other methods could be applied). However, as we would expect 5% of comparisons to be statistically significant due to chance alone, this translates to less than one when looking at the 8 correlation coefficients calculated for TD. In addition, looking at the pattern of results, they do not seem to be random; TD was related to other types of unusual dreams and to teeth tension, in the expected directions. Thus, our results are probably not due to chance. Finally, future research may also explore the potential connections between several other sources of physical/somatic stimuli and other typical dreams, for instance flying, falling, or being frozen or unable to move (Yu, 2016). This may be an interesting way of studying the incorporation of sensory phenomena into dreams. Studies in the field of incorporation have usually focused on the prevalence of incorporation (i.e., the chances that a stimulus will be incorporated), using experimental methods; but much less is known on the dream mechanisms that distort the incorporated content. The present study preliminarily suggests that sensations of tension in one's teeth during sleep may be translated by the sleeping consciousness to images of teeth rotting or falling out. Such distortion to an emotionally salient image may be related to the activity of the amygdala during REM sleep (Dang-Vu et al., 2007). Perhaps psychobiological research is needed in order to further understand why or how this translation comes about. Notably, to the extent that these results will replicate in future studies with at least moderate effect sizes, they may be of practical significance. Specifically, since it is common for people to be unaware of their habit to grind or clench their teeth during sleep, TD may perhaps serve as indicators of undiagnosed bruxism, and thus may be utilized by dentists as an aid for screening of dental problems.

To the best of our knowledge, the present study is the first to empirically validate the hypothesized connection between TD and nocturnal dental stimulation or irritation. The findings seem to imply that TD are most likely affected by physical sensations over the alternative hypothesis, according to which TD have a symbolic psychological meaning, representing psychological distress. Future studies are needed in order to replicate this effect (especially due to the small-to-medium effect size in this study) and expand this research line to other prevalent dream themes. Nevertheless, this preliminary study is a first step for understanding physiological effects on the production of common or universal dreams.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this manuscript will be made available by the authors, without undue reservation, to any qualified researcher.

AUTHOR CONTRIBUTIONS

NR and NS-D designed and conceptualized the study, recruited the sample, collected and analyzed the data, conducted the literature search, and wrote the manuscript.

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Dream Recall Frequency Is Associated With Medial Prefrontal Cortex White-Matter Density

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Recent findings indicate that dream recall frequency (DRF) is associated with neurophysiological traits, and notably the regional cerebral blood flow at rest within the medial prefrontal cortex (MPFC) and the temporo-parietal junction (TPJ). To test whether, such physiological traits are rooted in anatomical specificities, we used voxel-based morphometry to compare the white matter and gray matter density in regions related to dream recall (either at the experimental or theoretical level, MPFC, TPJ, hippocampus and amygdala) between 46 high dream recallers (HR, DRF = 5.98 ± 1.25 days per week with a dream report) and 46 low dream recallers (LR, DRF = 0.34 ± 0.29). We found an increased medial prefrontal cortex white-matter density in HR compared to LR but no other significant difference between the two groups. These results are consistent with previous studies showing that lesions within the white matter of medial prefrontal cortex are associated with a partial or total cessation of dream reporting and suggest an implication of this region in dream recall or, more likely, in dream production.

Keywords: dreaming, dream recall, voxel-based morphometry, sleep, MRI, hippocampus, amygdala, DMN

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INTRODUCTION

While dreaming has long been considered as the cognitive correlate of rapid eye movement (REM) sleep, it is now well established that dreaming can occur in any sleep stage and is therefore not exclusive to a specific sleep stage (Solms, 2000; Nir and Tononi, 2010; Ruby, 2011; Montangero, 2018). It is consequently currently out of reach to know for sure when one is actually dreaming while asleep (i.e., no physiological marker of dreaming has been discovered yet). For that reason, most empirical investigation of dreaming (be it the investigation of dream content, or frequency) are based on the study of dream memories reported after the awakening of the dreamer (e.g., Schwartz and Maquet, 2002; Fosse et al., 2003; Schredl et al., 2003; Schwartz, 2003; Zadra and Robert, 2012; Windt, 2013; Vallat et al., 2017a). Studies on dreaming have thus highlighted the cognitive and cerebral correlates of dream recall, either by investigating the EEG in the minutes preceding an awakening followed (or not) by a dream recall (Esposito et al., 2004; Wittmann et al., 2004; Chellappa et al., 2011; Marzano et al., 2011; Scarpelli et al., 2015; Siclari et al., 2017), or by

Abbreviations: BMI, body mass index; DMN, default mode network; DRF, dream recall frequency; EEG, electroencephalography; fMRI, functional magnetic resonance imaging; HR, high dream recallers; LR, low dream recallers; MPFC, medial prefrontal cortex; PET, positron emission tomography; rCBF, regional cerebral blood flow; TPJ, temporoparietal junction; VBM, voxel-based morphometry.

evaluating the cognitive and brain functioning associated with high and low DRF using behavioral methods, EEG or fMRI (Ruby, 2011 for a review; Eichenlaub et al., 2014a,b; Vallat et al., 2017b, 2018a).

Using this last strategy, recent works from our team highlighted several neurophysiological differences between HR (more than 3 days per week with a dream recall) and LR (less than 2 days per month with a dream recall), not only during sleep but also during wakefulness (Eichenlaub et al., 2014a,b; Vallat et al., 2017b). Notably, using PET, we compared the spontaneous rCBF of HR and LR during sleep and wakefulness, and showed that HR have a higher spontaneous rCBF than LR in the temporo-parietal junction (TPJ) and in the MPFC during REM sleep, N3 sleep and wakefulness (Eichenlaub et al., 2014b).

We concluded that these two regions played a key role in dream production or recall since lesions of these same areas have been found to be consistently associated with global or partial cessation of dream reporting (without any concurrent sleep disturbance; see Solms, 1997, 2000).

To our knowledge, only one study has so far investigated the relationship between brain anatomy and dream recall (De Gennaro et al., 2011). In this study, the authors used multiple regression analysis to evaluate the linear relationships between measures of some deep gray matter structures (amygdala and hippocampus) and quantitative and qualitative aspects of dream reports. They reported that the neuroanatomical measures were not associated with the number of dreams recalled per day, but they were with some features of dream reports such as length, emotional load, bizarreness, and vividness.

In the present study, we intended to further test the possible association between brain anatomical structures and dream report frequency. In line with previous results, we targeted brain regions previously associated with dream recall at the experimental or theoretical level (MPFC & TPJ, Solms, 1997; Eichenlaub et al., 2014b; hippocampus and amygdala, Maquet et al., 2005; Levin and Nielsen, 2007; De Gennaro et al., 2011; Perogamvros and Schwartz, 2012; Llewellyn, 2013; Malinowski and Horton, 2015). We expected that HR would show an increased density of the gray-matter and/or white-matter in the MPFC and/or the TPJ but would not show such an increase in the hippocampus and the amygdala.

METHODS

Participants

Data for this study comes from two distinct neuroimaging studies (Eichenlaub et al., 2014b; Vallat et al., 2018b). In both studies, the main inclusion criterion was self-reported habitual weekly DRF, assessed by questionnaires (Vallat et al., 2018a). The inclusion criteria for HR were at least 3 days per week with a dream recall, and for LR, at most 2 days per month with a dream recall. No subjects had a history of medical, neurological, or psychiatric disease or was on medication at the time of the studies. The subjects provided written informed consent according to the Declaration of Helsinki. The studies were approved by the local ethics committee (CCPPRB, Centre Leon Berard, Lyon, France), and the subjects were paid for participation.

The anatomical scans acquired during wakefulness of 92 participants were analyzed (mean age = 22.45, standard deviation = 2.23, range = 19–29). Among them, 46 were HR and 46 were LR. As can be seen in **Table 1**, the two groups differed significantly in DRF, but not in age, sex ratio and body mass index (BMI).

MRI Data Collection

Structural data for both studies were acquired at the CERMEP neuroimaging facility in Lyon, France. In Study A (21 HR and 20 LR) (Eichenlaub et al., 2014b), structural MRI were acquired with a T1-weighted MPRAGE sequence (1.0 mm isotropic resolution) on a 1.5T Siemens Sonata MR system (Siemens Medical Solutions, Erlangen, Germany). In Study B, structural MRI were acquired with a T1-weighted MPRAGE sequence (0.9 mm isotropic resolution) on a 3T Siemens Primage MR system (28 HR and 27 LR, Vallat et al., 2018b). Out of the 96 subjects, four were excluded based on age or BMI outlier rejection.

VBM Analyses

Preprocessing

Prior to preprocessing, all raw images were visually inspected for potential artifacts. Data preprocessing was performed using the CAT12 toolbox[1] (Gaser and Dahnke, 2016) for SPM12 (Wellcome Department of Cognitive Neurology). Data were normalized to MNI stereotactic space using DARTEL registration (Ashburner, 2007), corrected for bias field inhomogeneities, and segmented into gray matter, white matter, and cerebrospinal fluid. The mean correlation and weighted overall image quality were then computed and visually plotted to perform quality check and outlier rejection. The mean correlation measures the homogeneity of the data after pre-processing, whereas the weighted overall image quality combines measurements of noise and spatial resolution of the image before preprocessing. Four participants were excluded from further analyses because of a low data quality (one HR and one LR from Study A, one HR and one LR from study B). For the remaining 88 participants, we estimated the total intracranial volume (TIV) to further correct for different head size and volume. Images were then smoothed with an isotropic Gaussian kernel of 6 mm full width at half-maximum.

[1] http://www.neuro.uni-jena.de/cat/

TABLE 1 | Group demographics. *P*-values were obtained using two-sided *t*-tests for age, DRF, and BMI and using chi-square for the sex ratio.

	n	Age	Sex ratio (M/F)	Habitual Weekly DRF	BMI
Mean HR	46	22.52	2.1	5.98	22.63
STD HR	–	*2.22*	–	*1.25*	*2.36*
Mean LR	46	22.38	2.8	0.34	22.45
STD LR	–	*2.26*	–	*0.29*	*2.50*
p-value	–	*0.77*	*0.49*	*<0.001*	*0.71*

Statistical Design

The normalized modulated smoothed white and gray matter images were entered into an independent two sample *T*-test statistical model, together with age and TIV as covariates. We restricted the analyses to the MPFC, TPJ, hippocampus and amygdala (**Supplementary Figure S1**). A single binary spatial mask comprising these four regions was created by combining the individual and thresholded spatial masks of each of these regions (using the *fslmaths* command). The individual spatial masks were defined by generating a map in Neurosynth[2], using the keywords 'amygdala,' 'hippocampus,' 'medial prefrontal,' and 'temporoparietal junction,' respectively. The four maps were then thresholded at $z = 7$ to increase anatomical specificity. The significance threshold was set at $p < 0.001$ uncorrected with an extent threshold of 10 voxels.

RESULTS

We did not find gray matter density differences between HR and LR. However, VBM analyses revealed an increased MPFC white-matter density in HR compared to LR (peak cluster in MNI coordinates = 3, 56, 11; extent = 172 voxels; **Figure 1**).

DISCUSSION

This study intended to test whether an increased DRF in HR could be associated with gray- or white- matter density specificities in brain regions previously associated (at the theoretical or experimental level) with dream recall and/or production, namely the amygdala, hippocampus, MPFC and TPJ. VBM analyses of the anatomical scans of 44 HR and 44 LR revealed a significant difference between the two groups in the white matter of the MPFC. This result adds an anatomical dimension to numerous experimental findings showing differences in brain functioning between HR and LR (Eichenlaub et al., 2014a,b). To the best of our knowledge, this is the first study reporting brain structural differences between HR and LR.

The absence of a significant group difference in the amygdala and hippocampus replicate previous results (Torda, 1969; De Gennaro et al., 2011) and support the idea that these two regions are not directly involved in dream memory frequency, even if they might be involved in some qualitative aspects of dream content (Torda, 1969; Maquet and Franck, 1997; Revonsuo, 2000; Maquet et al., 2005; Nielsen and Stenstrom, 2005; De Gennaro et al., 2011; Solms, 2013; Corsi-Cabrera et al., 2016).

The significant group difference in the white-matter of the MPFC is well in line with previous neuropsychological findings showing a cessation of dream reports after lesion in the white matter surrounding the frontal horns of the lateral ventricles (Solms, 1997, 2000). To explain this observation, Solms stressed that the ventromedial prefrontal cortex contains a substantial number of fibers connecting frontal and limbic structures with dopaminergic cells in the ventral tegmentum. He further suggested that dreaming is generated by this dopamine circuit, i.e., that the mesocortical-mesolimbic dopamine system plays a causal role in the generation of dreams (Solms, 2000). Our results support this conclusion by showing in healthy subjects a significant association between DRF and the white matter density in the MPFC. To assess whether it is an acquired or an innate characteristic, and to better understand the functional significance of a white matter density increase, future studies may measure the white matter density in the MPFC before and after an increase of DRF induced by an increase in attention to, or interest in dreams (as can be done with a dream diary, Schredl, 2002; Ruby, 2011).

At the functional level, some EEG studies have produced results compatible with an involvement of MPFC in dream recall (e.g., a positive association between increased frontal theta EEG power and successful dream recall, Marzano et al., 2011; Scarpelli et al., 2015) and a PET study has demonstrated an increased cerebral blood flow in the MPFC during sleep in HR as compared to LR (Eichenlaub et al., 2014b). This last result suggests that MPFC plays a role in dream production rather than in dream recall due to its tonic activity during sleep. In addition, previous results did not noticeably involve MPFC in memory

[2]http://neurosynth.org/

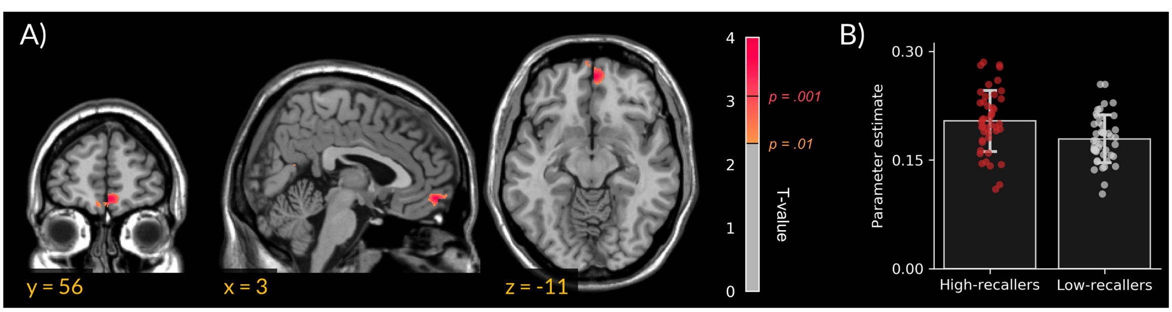

FIGURE 1 | Increased medial prefrontal cortex white-matter density in high dream recallers. **(A)** Statistical parametric map showing an increased white-matter density in HR (*N* = 44) as compared to LR (*N* = 44; peak cluster in MNI coordinates = 3, 56, –11). For display purpose, threshold was set at $p < 0.01$ uncorrected. **(B)** Bar plots of cluster-averaged parameter estimate in both groups. Points represent individual values.

recall. Rather, this region is involved in social cognition such as mind reading (Legrand and Ruby, 2009 for a review), social emotions processing (e.g., Ruby and Decety, 2004) and projective imagery (i.e., envisioning the future or the past, Buckner and Carroll, 2007). As such, it could participate in the production of the scenario or plot of the dream. This is consistent with results showing a similar level of rCBF in the MPFC during wake and REM sleep and an important drop of activity in this region during N3 sleep, a sleep stage associated with less dream reports than REM sleep (Nielsen, 2000; Maquet et al., 2005; Ruby, 2011). This interpretation is well in line with recent review articles arguing that dreaming is an intensified form of mind wandering and that at least part of the DMN of the brain (of which the MPFC is a core component, Gusnard and Raichle, 2001; Raichle et al., 2001) is involved in the production of dreams (Domhoff, 2011; Domhoff and Fox, 2015; Christoff et al., 2016). The DMN is a set of functionally coupled brain regions especially during internally oriented mental processes and episodic memory retrieval (Gusnard and Raichle, 2001; Raichle et al., 2001; Legrand and Ruby, 2009). This network is centered on the MPFC, the posterior cingulate cortex (PCC) and the lateral parietal areas around the TPJ area but also comprises the temporal pole and the hippocampus and parahippocampal gyrus (Legrand and Ruby, 2009; Raichle, 2015).

Finally, it should be noted that in this study, we investigated the possible brain anatomical correlates of the trait component of DRF. Yet, DRF has both trait and state components (Schredl and Reinhard, 2008; Ruby, 2011; Eichenlaub et al., 2014a,b). The state components of DRF mediated by, for example, sleep stage, time of night, the pre-sleep mood, or psychotropic drug use (Stickgold et al., 2001; Schredl, 2007; Nir and Tononi, 2010; Ruby, 2011; Tribl et al., 2013) most probably has functional rather than anatomical neurophysiological correlates (e.g., Esposito et al., 2004; Chellappa et al., 2011; Marzano et al., 2011; Scarpelli et al., 2015).

The main finding of this article is that, as compared to LR, HR show an increased white matter density in the MPFC. Altogether with previous functional (PET, EEG) and neuropsychological (lesions) results, our finding argues for a role of the MPFC in dream production.

AUTHOR CONTRIBUTIONS

AN, J-BE, RV, and PR participated in designing the study and collecting data. RV conducted the data analysis and wrote the first draft of the paper. PR participated in the writing of the article.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2018.01856/full#supplementary-material

FIGURE S1 | Spatial mask used in the VBM analysis. MPFC, medial prefrontal cortex. TPJ, temporoparietal junction.

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Testing the Empathy Theory of Dreaming: The Relationships Between Dream Sharing and Trait and State Empathy

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In general, dreams are a novel but realistic simulation of waking social life, with a mixture of characters, motivations, scenarios, and positive and negative emotions. We propose that the sharing of dreams has an empathic effect on the dreamer and on significant others who hear and engage with the telling of the dream. Study 1 tests three correlations that are predicted by the theory of dream sharing and empathy: that trait empathy will be correlated with frequency of telling dreams to others, with frequency of listening to others' dreams, and with trait attitude toward dreams (ATD) (for which higher scores indicate positive attitude). 160 participants completed online the Toronto Empathy Questionnaire and the Mannheim Dream Questionnaire. Pearson partial correlations were conducted, with age and sex partialled out. Trait empathy was found to be significantly associated with the frequency of listening to the dreams of others, frequency of telling one's own dreams to others, and attitude toward dreams. Study 2 tests the effects of discussing dreams on state empathy, using an adapted version of the Shen (2010) state empathy scale, for 27 pairs of dream sharers and discussers. Dream discussion followed the stages of the Ullman (1996) dream appreciation technique. State empathy of the dream discusser toward the dream sharer was found to increase significantly as a result of the dream discussion, with a medium effect size, whereas the dream sharer had a small decrease in empathy toward the discusser. A proposed mechanism for these associations and effects is taken from the robust findings in the literature that engagement with literary fiction can induce empathy toward others. We suggest that the dream acts as a piece of fiction that can be explored by the dreamer together with other people, and can thus induce empathy about the life circumstances of the dreamer. We discuss the speculation that the story-like characteristics of adult human dreams may have been selected for in human evolution, including in sexual selection, as part of the selection for emotional intelligence, empathy, and social bonding.

Keywords: dreaming, empathy, social simulation, dream sharing, human bonding, human evolution and behavior, human consciousness, consciousness

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INTRODUCTION

In general, dreams are a novel but realistic simulation of waking social life, with a mixture of characters, motivations, scenarios, and positive and negative emotions. We propose that the sharing of dreams has an empathic effect on the dreamer and on significant others who hear and engage with the telling of the dream. This suggested post-sleep effect of dreams can be contrasted with theories of within-sleep functions, such as that dreams reflect memory processing during sleep (Walker and Van der Helm, 2009; Blagrove et al., 2011a,b; Wamsley and Stickgold, 2011, 2018; Wamsley, 2014; van Rijn et al., 2015; Eichenlaub et al., 2018; Scarpelli et al., 2019), or reflect pre-sleep emotional waking life (Schredl, 2006; Malinowski and Horton, 2014; Blagrove et al., 2019).

Dreaming and Personal Insight

There has been much work on the effects on the dreamer of telling and discussing dreams. Edwards et al. (2013) showed that the dreamer obtains deepened self-perception and personal gains from participation in sessions that follow the Ullman (1996) group dream discussion procedure. Edwards et al. (2013) distinguished between insight about the memory sources of an item of dream content and insight about one's waking life as a result of considering the dream. These two forms of insight, and level of engagement in discussing, exploring and working with the dream, contribute to the score on the exploration-insight subscale of the Gains from Dream Interpretation questionnaire (Heaton et al., 1998). Scores on this exploration-insight subscale were found to be very high after dream discussion and comparable to scores from Hill's well-established therapist-led dream interpretation method (Heaton et al., 1998). Edwards et al. (2015) showed that exploration-insight scores are greater for considering dreams than for considering a recent personally significant event, where both sets of reports were discussed and explored using the Ullman procedure. Furthermore, in Blagrove et al. (2019), participants rated discussions of dreams significantly higher than discussions of daydreams on exploration-insight, and also rated the statement "I learned more about issues in my waking life" more highly from discussing a dream than from discussing a daydream. These latter results were obtained even though participants did not select the dreams, as these were collected in the sleep laboratory, whereas home dreams can often be selected for sharing on the basis of appearing to be interesting, intriguing, useful or impactful.

In Blagrove et al. (2019), after approximately 50% of Rapid Eye Movement (REM) and non-REM (NREM) dream discussions, participants were able to describe some insight about their life that had resulted from the discussion. These insights were often not astounding, but showed that the dream content could act as a reminder, a reference to what might be being ignored in waking life. Many of the references to waking life were metaphorical, which accords with the extensive literature on dreams and metaphor. For example, Davidson and Lynch (2012) provide experimental evidence for the figurative or metaphorical expression of waking life emotional experiences in dream content, as well as literal representations, and Malinowski and Horton (2015) detail how metaphor and hyperassociativity are imagination mechanisms behind emotion and memory assimilation in sleep and dreaming. On this, using the theory of conceptual metaphor, Lakoff (1993) shows how metaphors structure cognition in waking life and in dreaming, in that abstract ideas are thought about in terms of more basic, often concrete ideas. For example, he details the LOVE IS A JOURNEY metaphor, which enables circumstances and experiences concerning love to be thought of in terms of journeys. In contrast to the view that metaphors in dreams can elicit personal insight, Graveline and Wamsley (2015) state that there is "no evidence that dream content is any more symbolic than our waking cognition," and that waking cognition and dream content are both a "relatively transparent amalgam of our daily thoughts, feelings, and experiences." Contrary to this, we would hold that metaphors in waking life cognition and in dreams can often require considerable reflection to identify and understand, even sometimes needing the assistance of others.

Dreaming and Empathy

As a result of the work on dreaming and personal insight, and so as to give individuals greater time to discuss and consider their dreams, Mark Blagrove and artist Julia Lockheart started an arts science collaboration, DreamsID (Dreams – Interpreted and Drawn; DreamsID.com), in which dreams are shared by the dreamer and discussed with him or her in a one hour consultation period, using the Ullman (1996) method, and simultaneously drawn and painted. After this session the dreamer is given the artwork capturing the dream, to display and return to across time, on their own or with significant others. The aim was to aid the socialization and consideration of the dream narrative and its metaphors across a time period of many months and even years. However, whereas the project was devised so as to elicit insights for the dreamer from the discussion and artwork, in undertaking the project it became apparent that there was an emotional effect on the discusser and artist, and on the significant others of each dreamer, who listen to and engage with the dream and artwork.

Previous researchers have investigated the effects of sharing dreams. In a sample of undergraduates, Vann and Alperstein (2010) found 97.9% had told a dream to someone else at least once, and that dreams were told in order to entertain, or to elicit a reaction, or to share, and concluded that dream sharing may serve as a means to bring individuals closer together. Ijams and Miller (2000) explored the reasons individuals offer for revealing dreams to an intimate other, and for concealing dreams. Results indicated that dream-disclosure enhanced feelings of intimacy and trust within established relationships, provided the others' response was anticipated to be supportive and non-judgmental. Dream sharing can also enhance marital relationships through providing a forum for self-awareness and self-disclosure (Duffey et al., 2004).

Schredl and Schawinski (2010) found that about 14.5% of dreams are shared, mainly with romantic partners, friends, and relatives, and that the sharing is often associated with enhancement of relational intimacy and stress relief (for example, in the case of nightmares). Emotional intensity of the dream is the main predictor of social sharing for both negative and positive dreams (Curci and Rimé, 2008). Schredl et al. (2015a) found that, in a sample most of whom were psychology students, dreams were shared on average about 2 to 3 times per month, and the sharing was mostly with friends and spouses. At the time of completing questionnaires for the study about two thirds of participants had in the previous month told a dream to someone else, and two thirds had listened to a dream of someone else; furthermore, in the previous week, one third of participants had told a dream to someone else, and one third had listened to someone else's dream. Regarding the last situation in which the participant had told one of his/her own dreams to another person, or listened to a dream told by another person, the three main motives for dream telling were "dream topic relevant for the interaction between the dreamer and the listener," "extraordinary dream," and "wish to understand the dream better." The authors concluded that dream sharing is common and can affect the relationship between the dreamer and the recipient, and that reactions to dream accounts are more positively than negatively toned. Relevant here, although not addressing the sharing of dreams, are the findings of Selterman et al. (2014), that frequency with which participants dreamt of their romantic partners was positively associated with the extent to which they interacted with their partners, and that participants felt more love/closeness on days subsequent to dreaming about them, although dreams of infidelity resulted in less intimacy on subsequent days.

McNamara (1996) reviews evidence that REM sleep is designed to promote social bonding, that it may reactivate the systems utilized by infants to attach to a care-giver, and proposes that this may be reflected in dream content showing "bonding themes," especially in individuals not currently attached. McNamara et al. (2001) found that insecurely attached participants were more likely to (a) report a dream, (b) dream "frequently," and (c) evidence more intense images, with, they conclude, REM sleep and/or dreaming functioning, in part, to promote attachment. They propose that dreaming might shape daytime behaviors through activation and processing of persistent attachment related themes in dream content, given that relationship themes are quite frequent in dreams, and with the dream doing "serious emotional work," often with unpleasant content.

From the above review it is clear that the sharing of dreams is common, and that positive interpersonal effects occur as a result of such sharing. It is thus plausible that dream sharing could elicit or be associated with empathy as part of these interpersonal effects. The most obvious reason why dreams would be able to have this relationship with empathy is their high social content. In the Social Simulation Theory (SST) of Revonsuo et al. (2016), dreams are a simulation of waking social life, with a mixture of characters, motivations, scenarios, and positive and negative emotions. Social interactions in dreams simulate the social skills, bonds, interactions and networks that we engage in during our waking lives. For example, Tuominen et al. (2019) found that at least one social situation was present in 83.5% of dream reports, and dreams were found to have more social content than corresponding waking life reports (63.8%). Domhoff and Schneider (2018) similarly characterize dream content as the embodied enactment of waking life conceptualizations and concerns, and report that only 6.5% of dream reports are not social simulations. Theirs is, however, a non-functional view, as they note the presence of long-term concerns in dreams, and social interactions with deceased loved ones across years and decades, and past misfortunes, which they say are not characteristic of SST "forward-looking social rehearsal."

Dreaming, Fiction, and Empathy

Aside from the considerable evidence that dream content is related to waking social life, a further component supporting a link between dreaming and empathy is that the dream acts as a piece of fiction, which is explored by the dreamer and others as part of the sharing process, and that, like literary fiction (Oatley, 1999; Matthijs Bal and Veltkamp, 2013), can induce empathy about the life circumstances of the dreamer. In the Mind in the Eyes test (Baron-Cohen et al., 2001), participants view 36 photographs, each showing only a person's eyes, and choose from four adjectives to indicate what each photographed person was thinking and feeling. This is a behavioral test of empathy. Mar et al. (2006) used the Mind in the Eyes test to show a correlation between amount of reading fiction and trait empathy. This association was replicated by Mar et al. (2009), who showed that it was not due to personality variables related to both frequency of fiction reading and empathy. Matthijs Bal and Veltkamp (2013) showed that empathy was increased over a period of 1 week for people who read a fictional story, in comparison to a non-fictional piece, but that this effect only occurred if the reader was fully immersed into the story, "transported into this narrative world." They state that the emotional response is greater than with non-fiction, because of the involvement with the characters and story, and because "the focus of fiction is primarily on eliciting emotions, rather than on presenting factual information...," and that the reader sympathizes with the characters in the story, through taking the perspective of the characters, and experiences the events as if they are the reader's own experience.

Our drawing a comparison between dreams and literary narrative does raise two questions, on the measurement of the narrative structure of dreams, and on the difficulties associated with deciding what is literary about literary narratives. On the first of these questions, Nielsen et al. (2001) quantified narrative progression in REM and NREM dreams using a story grammar tool to parse dream reports into their constituent components (actions, scenes, and characters) and to identify the causal precursors and consequences of the constituent actions. The two types of sleep did not differ with respect to the mere presence of story components. Episodic progression, that is, the minimal story unit, was defined as the occurrence of at least one character action for which both an initiating event and a consequence were also identified. A greater proportion of REM than NREM stage 2 reports contained at least one episodic progression, proportions were, respectively, 0.66 and 0.43. This significant difference was accounted for by the proportion of dreams with episodic progression being much higher (0.79) for late REM dreams of frequent dream recallers.

On the question of what is a literary narrative, Mar and Oatley (2008) include in this category novels, films, TV dramas, and theater, and state that these narratives model and abstract the human social world, and with the viewer, listener or reader undergoing a simulation of events. For a definition of literary narrative, they state that this includes "a series of causally linked events that unfold over time," with "relationships among individuals and the navigation of conflicting desires." They state that these narratives are "carefully crafted, written, and rewritten by authors intending their products for public consumption," and "offering a form of cognitive simulation of the social world with absorbing emotional consequences for the reader." Some of these characteristics of literary narrative obviously do not hold for dreams, but for the present paper the crucial characteristics that they have in common are that literary narratives and dreams are simulations of the waking social world, and that both can elicit engagement and emotion when told.

The brain basis for story production in dreams is detailed in Pace-Schott's (2013) *Dreaming as a story-telling instinct*. The similarity between dreams and fictional stories is explored by States (1993), with dreams doing "much the same thing as the fiction writer who makes models of the world that carry the imprint and structure of our deepest concerns. And it does this by using real people, or scraps of real people, as the instruments of hypothetical acts." States proceeds to describe "such narratives contributing to our formulation and recognition of patterns of experience," and including scriptural violations or scripts in conflict. He compares dreams to two types of narrative, life itself, from which the dream borrows its content, and fiction, which is "waking dreams designed for other people," and he cites Calvin Hall's conclusion that people incorporated into dreams are those to whom we have mixed feelings, or some tension.

In their paper *The function of fiction is the abstraction and simulation of social experience*, Mar and Oatley (2008) state that "Engaging in the simulative experiences of fiction literature can facilitate the understanding of others who are different from ourselves and can augment our capacity for empathy and social inference." They conclude that "In much of literature, the author challenges readers to empathize with individuals who differ drastically from the self," and they propose that narrative fiction represents "learning through experience." We emphasize that the functional SST and non-functional Domhoff views of dreaming both see the dream as fiction. Dreams are fictional because they have events that only very rarely copy waking life episodes (Fosse et al., 2003). Furthermore, in Vallat et al. (2017), an unknown dream environment occurs in just over 40% of dreams, and is significantly more frequent than an environment that is wholly or partly taken from waking life. (In contrast, other characters in the dream are more likely to be known than to be unknown or mixed).

Testing the Empathy Theory of Dreaming

To date, no study has addressed the relationship between empathy and dream sharing, and between empathy and attitude toward dreams, although previous work has shown that dream recall frequency is correlated with empathy (Rabinowitz and Heinhorn, 1985), and attitude toward dreams is associated with the frequency of dream sharing (Schredl and Schawinski, 2010). We propose that dream sharing can elicit empathy toward the dreamer in the individuals with whom the dream is shared and discussed, and might increase empathy from the dreamer toward those with whom the dream is shared. The present Study 1 tests three hypotheses that follow from this proposed empathic effect of dream sharing: that trait empathy will be correlated with dream telling frequency, with frequency of listening to others' dreams, and with positive attitude toward dreams.

Although a relationship between sharing dreams and empathy is plausible, there would be different possible explanations for this proposed relationship. Firstly, it may be that individuals high in empathy show an interest in the dreams of others, and due to connectedness to others wish to share their own dreams, and see dreams in general as worthwhile for sharing and considering. It may also be that there is an individual difference that is correlated with empathy and with these dream variables, such as, for example, Hartmann's trait of thin boundariness (Hartmann et al., 1991). A third possible mechanism is that the sharing of dreams increases empathy and mutual understanding. From the literature on frequency and effects of dream sharing this is plausible, and especially as reactions to dream accounts are more positively than negatively toned (Schredl et al., 2015a). To address this we conducted Study 2, the aim of which was to assess changes in empathy following dream discussion, differentiating between empathy by a dream sharer toward their discusser, and empathy by the discusser toward the dream sharer. The primary hypothesis is that the discusser will have increased empathy toward the dream sharer. A second hypothesis is that the dream sharer will have increased empathy toward the discusser. It is unclear whether the two members of the dyad will differ in their change in empathy due to the discussion, and so there is no hypothesized difference between them in this regard.

STUDY 1

Methods

Participants

A total of 160 participants (120 females, 40 males; mean age = 21.30 years, *SD* = 4.70) were recruited from social media sites and from the Swansea University Department of Psychology's experiment participation scheme. All participants gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Research Ethics Committee, Department of Psychology, Swansea University. The study was described to recruits as being about "reading, emotions and dreaming." We included questions about reading habits in the study so that it would be unclear to participants what our hypotheses were.

Procedure and Materials

Participants completed online the Toronto Empathy Questionnaire (TEQ; Spreng et al., 2009) and the Mannheim Dream Questionnaire (MADRE; Schredl et al., 2014). The TEQ has 16 items, each scored on a 5 point scale, anchored at Never (0) and Always (4), with half the items negatively scored. Example items are:

"It upsets me to see someone being treated disrespectfully."

"I become irritated when someone cries."

The total score is the sum of all item scores and can vary between 0 and 64.

The items used from the MADRE were:

"How often have you recalled your dreams recently (in the past several months)?" Participants responded on a 7 point scale, using points ranging from "almost every morning" (7) to "never" (1). The other points on the scale are: 6 = Several times a week; 5 = About once a week; 4 = Two or three times a month; 3 = About once a month; 2 = Less than once a month.

"How often do you tell your dreams to others?" Participants responded on an 8 point scale, using points ranging from "several times per week" (8) to "never" (1). The other points on the scale are: 7 = About once a week; 6 = Two to three times a month; 5 = About once a month; 4 = About two to four times a year; 3 = About once a year; 2 = Less than once a year.

The MADRE assesses Attitude toward Dreams (ATD) with 8 items each scored on a 5 point scale from "Not at all" (0) to "Totally" (4). The items are:

"How much meaning do you attribute to your dreams?"

"How strong is your interest in dreams?"

"I think that dreams are meaningful."

"I want to know more about dreams."

"If somebody can recall and interpret his/her dreams, his/her life will be enriched."

"I think that dreaming is in general a very interesting phenomenon."

"A person who reflects on her/his dreams is certainly able to learn more about her/himself."

"Do you have the impression that dreams provide impulses or pointers for your waking life?"

The scale ranges from 0 to 32.
An item not present on the MADRE was added:

"How often do you listen to others telling their dreams to you?" Participants responded on the 8 point scale, with points ranging from "several times per week" (8) to "never" (1).

Analyses

Pearson partial correlations were conducted between the trait empathy and dream variables, with age and sex partialled out. Analyses using a median split for the empathy variable were then conducted, with difference on dream variables computed by ANOVA for the high/low empathy categories, and with η^2 calculated as effect size.

Results

Table 1 shows descriptive statistics of the trait empathy and dream variables. These variables had a normal distribution with skewness < 0.92.

Table 2 shows sex differences for the empathy and dream variables, with independent samples *t*-test statistics for the differences. Females scored significantly higher on all variables, except for marginally higher for frequency of listening to dreams of others.

We next tested the associations between trait empathy and the dream variables. As reported above, males and females differed significantly on empathy, ATD, and dream telling frequency, with dream listening frequency marginally greater for females. We therefore partialled out sex from the correlations. For empathic concern and perspective taking, there is an inverse-U-shaped pattern across age, with middle-aged adults reporting higher empathy than both young adults and older adults (O'Brien et al., 2012). Our sample was aged 18 – 48 years, and did show this expected positive relationship between age and empathy within this age range ($r = 0.13$, $p < 0.05$ one-tailed). We thus also partialled out age from the correlations. The Pearson partial correlations are presented in **Table 3**, and confirm the hypothesized associations of trait empathy with ATD and with frequencies of telling and listening to dreams.

As dream recall frequency was significantly associated with dream telling frequency, trait empathy and attitude toward dreams, the correlations of trait empathy with frequency of telling dreams to others and with positive attitude to dreams could thus be confounded by frequency of the dreamer recalling dreams. In a further analysis dream recall frequency was thus also partialled out; the correlations of trait empathy with frequency of dream telling ($r = 0.26$, $p < 0.001$, $df = 155$) and with ATD ($r = 0.24$, $p < 0.005$, $df = 155$) remained significant.

TABLE 1 | Descriptive statistics of trait empathy and dream variables.

	Mean	*SD*	Min	Max
Trait Empathy	48.13	7.93	15	64
Attitude toward dreams	20.33	6.34	0	32
Frequency of telling dreams[1]	5.53	1.89	1	8
Frequency of listening to dreams[1]	5.61	1.74	1	8
Dream recall frequency[2]	5.04	1.33	1	7

[1] 8 point scale, using points ranging from "several times per week" (8) to "never" (1).
[2] 7 point scale, using points ranging from "almost every morning" (7) to "never" (1).

TABLE 2 | Sex differences for trait empathy and dream variables, with independent samples *t*-test statistics for the differences.

	Male		Female			
	Mean	*SD*	Mean	*SD*	*t*(158)	*p*
Trait Empathy	44.93	8.81	49.20	7.35	3.028	0.003
Attitude toward dreams	17.78	6.38	21.18	6.11	3.012	0.003
Frequency of telling dreams[1]	4.75	2.11	5.79	1.75	3.094	0.002
Frequency of listening to dreams[1]	5.18	2.01	5.76	1.62	1.853	0.066
Dream recall frequency[2]	4.68	1.29	5.16	1.33	2.007	0.046

[1] 8 point scale, using points ranging from "several times per week" (8) to "never" (1).
[2] 7 point scale, using points ranging from "almost every morning" (7) to "never" (1).

TABLE 3 | Pearson partial correlation co-efficients between trait empathy and dream variables, with age and sex partialled out, dfs = 156.

	Empathy	ATD	Fr Tell	Fr List
Attitude toward dreams	0.29***			
Frequency of telling dreams	0.32***	0.26***		
Frequency of listening to dreams	0.14*	0.20**	0.57***	
Dream recall frequency	0.19*	0.46***	0.46***	0.31***

$^*p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$ (ps are one-tailed).

TABLE 4 | Pearson partial correlation co-efficients between trait empathy and dream variables, with age, sex, dream sharing and ATD variables partialled out, dfs = 155.

	Empathy	Variables partialled out
Attitude toward dreams	0.23**	Dream telling frequency, age, sex
Attitude toward dreams	0.27***	Dream listening frequency, age, sex
Frequency of telling dreams	0.26**	ATD, age, sex
Frequency of listening to dreams	0.08	ATD, age, sex

**$p < 0.01$ and ***$p < 0.001$ (ps are one-tailed).

In order to investigate whether ATD accounts for further variance in empathy, beyond that explained by the two dream sharing variables, and whether the dream sharing variables account for empathy variance beyond that explained by ATD, further partial correlations were conducted, with these variables partialled out. **Table 4** shows that ATD remains significantly associated with empathy when dream sharing variables are partialled out, and frequency of telling dreams, but not listening to dreams, remains significantly associated with empathy when ATD is partialled out.

Analyses using a median split for the empathy variable were then conducted. Median value for empathy = 49.0, nine participants fell on the median and were excluded. Means (SDs) of empathy for the below (n = 77) and above (n = 74) median groups were 41.97 (6.46) and 54.43 (3.63) respectively. The below and above median groups were compared for ATD and dream sharing variables using ANOVA, with age and sex partialled out. **Table 5** shows that the below and above median groups differ significantly on ATD and dream telling frequency, and marginally on dream listening frequency.

To address the role of gender in the inferential findings we included the main effect of gender and the interaction of gender with empathy in the ANOVAs. There is a main effect of sex on frequency of telling dreams ($\eta^2 = 0.035$, $p = 0.023$) and on ATD ($\eta^2 = 0.061$, $p = 0.002$) and no main effect of sex on frequency of listening to dreams ($\eta^2 = 0.013$, $p = 0.174$) nor frequency of dream recall ($\eta^2 = 0.012$, $p = 0.179$). There was no interaction of sex with empathy as a predictor of these dream variables (listening, $\eta^2 = 0.017$; telling, $\eta^2 = 0.003$; ATD, $\eta^2 = 0.003$; dream recall frequency, $\eta^2 = 0.013$, all ps > 0.1). Females thus score higher on the empathy and dream variables than do males but there is no significant difference between males and females in their relationships between empathy and the dream variables.

STUDY 2

Methods

Participants

27 pairs of participants were recruited to the study, each pair had applied together, as friends or in a relationship, knowing that one would be sharing dreams and the other of the pair would discuss the dreams with them. The sharer was identified as the member of the pair with highest retrospective dream recall frequency. There was data loss for one dream sharer, and thus 53 participants overall were included in the analyses (22 males and 31 females; 18 – 23 years, mean age = 20.97 years, SD = 1.35), comprising 26 dream sharers and 27 discussers. All participants gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Research Ethics Committee, Department of Psychology, Swansea University.

Procedure

At the start of the study each participant completed online an adapted version of the 12-item Shen (2010) state empathy scale (see below), regarding empathy toward the other member of the pair. This produced a baseline empathy score for each participant toward the other member of their pair. Upon having a dream, the dream sharer arranged to meet the other member of the pair so as to discuss the dream with them. The discussion followed the stages of the Ullman (1996) dream appreciation technique, written instructions for which were given to dream sharers and discussers at the start of the study. The stages of the technique are as follows:

(1) Reading of the dream aloud by the dreamer, and clarification of the dream report by the discusser asking questions of the dream sharer.
(2) Brief statement by the discusser of what feelings they would have experienced if the dream were their own, and of how the discusser would see the dream in terms of their own life.
(3) The dream sharer can respond to anything said in stage 2, and then describes his/her waking life as a context for the dream, with particular emphasis on recent experiences and concerns.
(4) The discusser reads back the dream to the dreamer, in the second person, so that any additional information about the dream or the dreamer's waking life can be obtained.

TABLE 5 | Differences between below (n = 77) and above (n = 74) median trait empathy groups on the ATD, dream sharing and dream recall variables, with ANOVA statistics and η^2 effect size for each dream variable.

	Below median empathy		Above median empathy		Inferential statistics for comparison of below and above median groups		
	Mean	*SD*	Mean	*SD*	$F(1,146)$	p	η^2
Attitude toward dreams	18.82	7.01	21.80	4.99	7.076	0.009	0.046
Frequency of telling dreams	4.99	2.09	6.08	1.59	9.654	0.002	0.062
Frequency of listening to dreams	5.42	1.86	5.82	1.63	3.790	0.053	0.025
Frequency of recalling dreams	4.84	1.37	5.24	1.30	3.745	0.055	0.025

TABLE 6 | Baseline and post-dream discussion empathy of dream sharer (n = 26) and dream discusser (n = 27) toward each other, and change in empathy from baseline for sharer and discusser.

Role	Baseline empathy		Post-dream discussion empathy		Paired samples *t*-test		Change in empathy from baseline		Independent samples *t*-test
	M	*SD*	*M*	*SD*	*t*	*p*(1-tail)	*M*	*SD*	
Sharer	85.54	12.18	83.38	9.17	$t(25) = 1.037$	0.310	−2.15	10.59	$t(51) = 2.017$ $p = 0.049$ (2-tail)
Discusser	78.67	17.20	82.93	15.99	$t(26) = 1.780$	0.044	+4.26	12.44	

Number of sharer/discusser pairs = 27, data were lost for one dream sharer. Baseline empathy of sharers and discussers did not differ significantly [t(51) = 1.672, p = 0.10].

(5) Orchestration, in which the dream sharer and discusser suggest connections between information that the dreamer has given about his or her dream and information the dreamer has given about the dreamer's life.

The discussion duration was set at 15–30 min. Each participant completed the state empathy scale after the dream discussion. During the study the majority of participants had one dream discussion. (Some participants, progressively fewer each time, had 2 to 5 dream discussions as part of an unsuccessful attempt by the experimenters to obtain sufficient data for repeated-measures analysis.) The empathy score following the last or only dream discussion is used as the post-intervention measure, and compared to the empathy score measured at baseline.

Materials

Adapted Shen (2010) state empathy scale.

Each item is scored on a 0 – 10 scale, where 0 = not at all and 10 = completely.

(1) My friend's/partner's emotions are genuine.
(2) I experience the same emotions as my friend/partner.
(3) I have a similar mood to my friend/partner.
(4) I can feel my friend's/partner's emotions.
(5) I can see my friend's/partner's point of view.
(6) I recognize my friend's/partner's situation.
(7) I can understand what my friend/partner goes through.
(8) My friend's/partner's reactions are understandable.
(9) When I talk to my friend/partner, I am fully absorbed.
(10) I can relate to what my friend/partner goes through.
(11) I can identify with the situations my friend/partner describes to me.
(12) I can identify with my friend/partner.

Scores on the scale range from 0 to 120.

Analyses

It was predicted that each member of the pair will have a significant increase in empathy toward the other, and so these changes are assessed by one-tailed paired samples *t*-test. A difference between the change score of sharer and change score of discusser is not hypothesized, and so is assessed by two-tailed independent samples *t*-test. Effect size where a paired-sample *t*-test achieves significance ($p < 0.05$) was calculated as $d_z = t/\text{sqrt}(n)$ (Lakens, 2013) where n = number of participants. Following Cohen (1988, p. 40 and p. 46), thresholds for d_z are small effect = 0.14, medium effect = 0.35, and large effect = 0.57. Effect size for the independent sample *t*-test was calculated as $d_s = t \times \text{sqrt}(1/n_1 + 1/n_2)$, where n is the sample size for each independent group, and for which Cohen (1988) gives thresholds of small effect = 0.2, medium effect = 0.5, and large effect = 0.8.

Results

Table 6 shows that, as hypothesized, the dream discusser had an increase in empathy from baseline toward the dream sharer as a result of the discussion, with medium effect size of $d_z = 0.343$. The dream sharer had a non-significant decrease in empathy toward the discusser. The discusser had a significantly greater change in empathy score compared to the dream sharer, with medium effect size of $d_s = 0.554$.

DISCUSSION

The three hypotheses of Study 1 were confirmed: trait empathy was found to be significantly associated with frequency of listening to the dreams of others, frequency of telling one's own dreams to others, and positive attitude toward dreams. However, when ATD and dream sharing variables were used as covariates in the respective correlations the findings were that it was dream telling frequency and ATD that remained significantly associated with empathy. These relationships may be solely correlational, with high empathy people choosing to share dreams, or due to some other personality measure such as thin boundariness (Hartmann et al., 1991) being associated with empathy and with dream variables. The relationship between dream sharing and empathy also involves a belief in dreams being a worthwhile subject of deliberation and discussion, rather than solely a simple frequency of engaging in dream sharing. The possibility of a causal relationship was addressed in Study 2, where, as hypothesized, the dream discusser had a significant increase in empathy toward the dream sharer as a result of discussing dreams following the Ullman technique. However, contrary to our expectations, the dream sharer had a small decrease in empathy toward the discusser, and indeed the discusser had a significantly greater change in empathy as a result of the discussion than did the sharer. These latter findings, in retrospect, can be understood in that the dream sharer is addressing their own dream and own life during the discussion process, and so would not necessarily have a significant change in empathy toward the discusser. An increase in empathy for both members of a pair would thus need them to take turns in sharing and discussing.

The results from the two studies thus provide support for the empathy theory of dreaming. However, although accepting the results, a sceptical view could quote the often repeated claim that "There is nothing more boring than listening to someone else's dream!" The sceptical view would state that, although on an everyday basis (as opposed to formal dream sharing groups) people may choose to share their dreams with others, it could be argued that this is done so as to tell a particularly strange or unusual dream, and that while the other person will listen, they rarely engage with the dream beyond their mere (and at times polite) listening. Indeed, from the Study 1 data and review here, at best most people will share their dreams about once or twice a month – and this amongst people likely favorable toward dreams in general. Furthermore, people may agree to listen to others wanting to tell them a dream, as doing otherwise would be exceedingly rude. It could be argued that while positive interpersonal effects can occur, this might not be so for a majority (or even sizable minority) of spontaneous or everyday dream sharing. Furthermore, aside from maybe lacking genuine interest in the dreams that we are told, most people are not versed in ways of constructively reacting to and engaging with the relayed dream. If this is indeed the case, it may be argued that most people will do little more than listen to the dream – and that this, in fact, may well be the normal response to most shared dreams in everyday settings.

In response to this sceptical view, it may well indeed be that only a minority of recalled dreams are shared (approximately 14% of all recalled dreams were shared in a study by Schredl and Schawinski, 2010). Yet, it may be possible that even the small number of shared dreams bears an effect on empathy. In previous studies, 35% of respondents representing the general population share dreams at least monthly, and about 10% weekly or several times per week (Schredl et al., 2014), and in children and adolescents, sharing seems to be more frequent (Georgi et al., 2012). Thus, a significant proportion of the population engages in dream sharing regularly. Whereas Schredl et al. (2015a) found that negatively toned dreams are shared more often than positively toned dreams, for the most recent time a participant had heard someone else's dream, joy was a response for 63% of occasions. The main motives for sharing dreams include the dream topic being relevant for the interaction between dreamer and listener, the dream being extraordinary, for entertainment, to inform others of what is going on in the sharer's mind, to understand what the dream means, and interest in the opinion of others (Olsen et al., 2013). In cases of nightmares and negative dreams, dream telling is a means to seek relief for negative emotions elicited by the nightmare (Schredl and Göritz, 2014). Sharing strange and unusual dreams, or emotionally highly salient dreams, may be thus more frequent than sharing mundane dreams, but this probably also applies to sharing waking events as well. That the gender difference in dream sharing is related to frequency of sharing emotional experiences and to sex role orientation (femininity/expressivity), rather than dream-related variables such as dream recall frequency and ATD (Schredl et al., 2015b), suggests that dream sharing can be a positive self-disclosure process.

Furthermore, data on how listeners respond to dream sharing show that boredom is not the most common reaction. Schredl et al. (2015a) report that laughter/amusement and sympathy are the most common reactions, accounting for about 35% and 23% of responses respectively, with only 10% of reactions being neutral or there being no response, and with the most common emotions associated with dream listening being astonishment, joy, grief, and the dream being seen as strange. In a recent study, Schredl and Göritz (2018) found that 21% of respondents report enjoying listening to dreams "very much," and 35% "much," with 6% responding with "not at all." Regarding the last-remembered situation in which a dream was told to the participant, the emotional reaction was most often positive (49.2%), with 45% of the participants rating the last listening experience as neutral, and only 2.1% as negative. Although this online sample may have been biased toward people who are interested in dreams, the sample was representative of the general population and with heterogenic demographic backgrounds (sample was of 935 women and 655 men, mean age = 51.20, range 17 to 93 years). It is thus plausible that listeners are not uninterested in other people's dreams, nor emotionally indifferent. This is also supported by Schredl and Göritz's (2018) findings that after the most recent dream listening situation percentages of further responses were, "I thought about the dream" (19%), "I talked again with the person about the dream" (20%), "I feel more close to the person who shared the dream" (13%), "I talked with others about the dream" (5%), and "I learned something about myself" (1.6%), these being overall marginally more frequent reactions than "I did not do anything more with the dream" after listening to it (45%). In summary, the findings reviewed here support a view that in general listening to the dreams of other people is a positive experience emotionally and in terms of social interaction.

Dreaming and Narrative

Using a microstructural approach, Montangero and Cavallero (2015) found that dreams are predominantly "continuous," but with most dreams having one or more "complications," defined as unexpected events creating change and a certain tension. They state that continuity and complications are both necessary for narrative, but that dream reports were not found to be structured like canonical stories, which would have semantic unity, growing tension, and the presence of an ending. Similarly, Montangero (2012) reviews theories and evidence on dreaming and narrative to show that although comprising sequences of usual and unusual events, with protagonists and motivations, dreams do not in general show the well organized structure of canonical stories. For the current paper, it may be that this lesser level of narrative is sufficient for the empathic effects of dream sharing. It may even be, as noted by Montangero (2012), that although the lack of executive functioning in sleep results in dreams not being formally story-like, it allows creative possibilities for representing our concerns in dreams. The manner of representation in dreams is further addressed by Walsh (2010), who describes the ambiguous status of dreaming, as experience and as narrative, and where there is a reciprocal process of creation and reception. This experiential component of dreaming makes it a special case of narrative, and one for which he suggests theoretical accounts of narrative may have to accommodate.

Relevant also to a loose form of narrative is Bulkeley's (2019) proposal that dreaming is imaginative play in sleep. He reviews play across species, and shows that dreaming shares the behavioral components of waking life human play, including practice, rehearsal, opening the mind to new possibilities beyond ordinary experience, and incorporating issues and concerns from waking social life. Bulkeley suggests that dreaming has many of the same functions as waking life play, and that dreaming may thus have been selected for this during human and mammalian evolution. The current paper, however, proposes a further use for dreams, that, when shared, they have effects on others, and which go beyond, albeit building on, the playful stretching of the mind of the dreamer that Bulkeley describes.

Evolution and Dream Sharing

There have been many theories that propose a within-sleep function of dreaming, for example, of threat simulation (Revonsuo, 2000), social simulation (Revonsuo et al., 2016), fear extinction (Levin and Nielsen, 2007), and the creation of weak or novel memory associations (Hartmann, 2011; Wamsley and Stickgold, 2011). These all hold that at the point of dream production, dream function occurs. What is proposed by the empathy theory is that there is (also) an effect that occurs later than dream production, when we are awake and share the dream. The empathy theory proposes that the often emotional dream simulation, if recalled, may have a lasting effect on the dreamer after sleep (through self-reflection), but also on significant others who are told and engage with the dream.

Possibly only McNamara et al.'s (2007) Costly Signaling Theory (CST) of dream recall and sharing has similarly proposed social effects of dream sharing on others from an experimental psychology standpoint, although we appreciate that this has been a frequent view in anthropology (e.g., Tedlock, 1987). The CST states that only signals or communications that are costly to produce will be seen as believable and not faked, and that, just as antlers are costly, so is REM sleep. Dreams are seen to give true information about the dreamer because they are involuntary and emotional, the dreamer signals on sharing that the dream was not invented, and shows that he or she can overcome the emotions of the dream. Dream sharing is thus a sign of strength or of good genes. As with the empathy theory, the CST posits that the long term result of advertising this honesty in communication is better social interactions for the individual. However, by contrast, the empathy theory emphasizes that others will come to an appreciation of the life circumstances and even vulnerabilities of the dreamer, rather than be impressed by their strength. Other differences between the empathy theory and CST are that the former prioritizes fiction and narrative that has to be explored by the dreamer and recipients, and that it is accepting of the fact that dreams are fakeable, in that a fake dream can still fulfil the self-disclosure function. In the empathy theory there are thus similarities between the told dream simulation and blushing, in that both signal the emotional state of the dreamer/blusher to others. Because the blush is involuntary, it is a believable signal about regret and about not wishing to transgress in the future, amongst the signaling of other emotions.

So far the proposal for this empathy effect of dream sharing, with mediation by the fictional content of dreams, is plausible and accords with the correlational and experimental findings reported here, but we now turn to a more speculative aspect. We speculate that the fictional/story-like characteristic of dreams may have been utilized or even enhanced in human evolution, and in human sexual selection, as part of the selection for emotional intelligence and empathy. This would be on a timescale similar to that for the evolution of language and storytelling as part of group cohesion and cooperation in humans (Smith et al., 2017).

A key component of the "mating mind" hypothesis (Miller, 2000) is that a wide range of behaviors that require significant intellectual ability, and are wasteful or irrelevant in terms of survival – behaviors such as music, complex language, or art - are actually honest signals of intelligence that have been selected for over a relatively short period of human history. Indeed, cranium size of human fossils show a steady and consistent growth over a period of around three million years, until anatomically modern humans emerged some 300,000 years ago with an approximately tripled brain size (Du et al., 2018). Arguably, this is too short a time for natural selection to increase brain size due to environmental pressure, and indeed, a larger cranium carries significant mortality costs during childbirth (Rosenberg, 1992). As such, sexual selection is likely to be the mechanism that has driven the increased brain size required for these behaviors.

A number of complex social behaviors seem to increase the attractiveness or likeability of the producer by those witnessing the behavior. For example, the creativity of male story-tellers contributes to their attractiveness beyond physical appearance (Watkins, 2017), and they are seen as more appealing when completing verbal and physical tasks (Prokosch et al., 2009). Related, these traits show significant genetic correlations, indicating heritability – a key component of any evolutionarily relevant trait (Verweij et al., 2014). More specifically, individuals skilled at story-telling, a behavior clearly associated with creativity, have greater mating success and are preferred social partners for cooperation, extending the benefits outside the domain of sexual reproduction (Smith et al., 2017). As such, creative individuals may benefit from creative signals both directly, in that it increases attractiveness, or indirectly, in that increased cooperation leads to greater networks.

Dreams and dream-sharing might have contributed to story-telling abilities (such as by providing material for stories) and possibly to empathy eliciting behaviors, with selection to increase positive social exchanges, mating related or otherwise, such as described in Dunbar's (2016) social brain hypothesis. This hypothesis holds that complex social life in primates has been the driving force behind increasing brain size, and that the relationship between brain size and group size is mediated, in humans at least, by mentalizing skills, which includes mentalizing about others and empathy. Dreams themselves might have originated from memory consolidation or threat rehearsal or other functions, or indeed might be no more than a spandrel, an epiphenomenon of sleep (Flanagan, 2000). However, as described by Barrett (2007), spandrels can become useful, in that: "A useful 'spandrel' immediately begins to evolve. To the extent that REM sleep supports dreaming, it emerged long ago – about the same time mammals appeared. There's been plenty of time for refinement – including of resulting cognitions." Thus, dreams may have been co-opted to add to story-telling abilities and empathy in humans. This possible empathy and bonding function of dreams would utilize the social characteristics of the simulation/dream, when the simulation/dream, on waking, is told to others. It may also utilize the architecture of sleep, in that the later REM periods, and especially the period closest to waking, are the longest, with greater story-like complexity and episodic progression in REM than in NREM dreams (Nielsen et al., 2001), and greater elaboration, length and complexity of dream-stories in later REM periods (Cipolli and Poli, 1992; Cipolli et al., 2015).

Implications for Consciousness

We can extend the arguments about dreaming in the present paper to consciousness more generally. Oatley (2016) in *Fiction: Simulation of social worlds*, states that people who read fiction improve their understanding of others, because fiction has complex characters and circumstances that we might not encounter in daily life. He concludes: "While some everyday consciousness can remain inside the individual mind and be externalized in small pieces during conversations, fictional stories can be thought of as larger pieces of consciousness that can be externalized by authors in forms that can be passed to others so that these others can internalize them as wholes, and make them their own." The present paper is proposing that dreams can, like fictional stories, be passed to others who internalize them as wholes. But what is being said of dreaming consciousness could also be said of the scenarios and narratives present in waking consciousness. A function of human consciousness could thus be that its content and narratives can be passed to and engaged with by others, resulting in second-person social benefits, and not just experienced in the first-person for access to (Block, 1995) and binding of emotional and cognitive processes.

Limitations

For Study 1, we acknowledge that whereas we used a uni-dimensional empathy questionnaire future research on the empathy theory should use measures that differentiate cognitive and affective dimensions, such as the Empathy Quotient (Baron-Cohen and Wheelwright, 2004) and the Questionnaire for Cognitive and Affective Empathy (Reniers et al., 2011). We would hypothesize that dream sharing is associated with both these dimensions. We also acknowledge that in this first study on this issue of dream-sharing and empathy we have used two simple behavioral measures of dream-sharing, that is, frequency of telling dreams and frequency of listening to dreams. We thus did not address interactive factors, such as motives for sharing a dream, levels of being attuned to or skilled in the discussion of dreams or other personally meaningful texts, and characteristics of dreams that are shared (or not shared). For example, Curci and Rimé (2008) differentiate the disclosure of emotionally positive and negative dreams and address the emotional intensity of shared dreams. We also did not examine the nature of the relationship with the person with whom the dream sharing is occurring (e.g., partner, friend, work colleague), nor individual differences in self-disclosure, nor factors that might affect disclosure, such as attachment styles. For example, individuals with insecure attachment orientations have been shown to limit their use of emotional disclosure as a means of emotion regulation (Garrison et al., 2012). Some of these factors might result in higher correlations of dream-sharing with empathy. In future work it will be necessary to address all these factors so as to elucidate mechanisms behind the relationship between dream-sharing and empathy, to compare the empathy theory with other theories of dreaming, and to relate this theory and findings to the more general literature on self-disclosure.

For study 2, again, a limitation is that we used a uni-dimensional empathy questionnaire. The main limitation, however, is that we did not use a comparison condition in which some meaningful narrative material other than a dream report was used as the basis for the discussion. Comparison conditions in future work could be the discussion of a recent significant event in the life of the dreamer, as used in Edwards et al. (2015), or the dream sharer telling someone else's dream to the listener in their dyad (Hill et al., 1993).

Regarding the general theory that dreaming is a form of fiction, we accept that we have not used or addressed sophisticated or differentiated theories of metaphor and of literary narrative, and have instead used simple versions of these concepts. Although we have referred to Lakoff and Johnson's (1980) theory of conceptual metaphor, future work should have regard to and assess metaphors on such variables as conventionality and aptness (Thibodeau and Durgin, 2011) and surprisingness, comprehensibility, and metaphoricity (Thibodeau et al., 2016). We have also not differentiated metaphor from other literary tropes, such as irony and synecdoche, as described by States (1989, 1997), instead going no further than the highly simple conceptualisation that metaphors are a non-literal representation of waking life, and which occur, as stated by Antrobus (1977), when the dream changes the context or attributes of waking life experiences. We acknowledge that a more differentiated account of non-literal representations is needed, and especially as the different tropes might afford different levels of creative restructuring of prior experience as part of the memory consolidation and cognitive flexibility and recombination functions of sleep and/or dreaming (Wagner et al., 2004).

Summary

Study 1 found that trait empathy is significantly correlated with frequency of telling dreams to others, frequency of listening to others' dreams, and positive attitude toward dreaming, and Study 2 found that dream sharing increases empathy in the listener/discusser toward the dream sharer. We propose that the dream acts as a piece of fiction, which others can explore with the dreamer and that, like literary fiction, can then induce interest in and empathy about the life of the dreamer. Increased dream telling across society might decrease differences between countries in levels of empathy (Chopik et al., 2017) and counteract current societal decreases in empathic concern and perspective taking, the main two components of empathy (Konrath et al., 2011).

ETHICS STATEMENT

The studies were carried out in accordance with the recommendations of the Research Ethics Committee, Department of Psychology, Swansea University with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocols were approved by the Research Ethics Committee, Department of Psychology, Swansea University.

AUTHOR CONTRIBUTIONS

MB, JL, MC, AJ, and KV conceived the manuscript. MB, JL, MC, and SH designed the Study 1. SH collected the data for Study 1. SH and MB analyzed the data for Study 1. MB, JL, and MC designed the Study 2. MB analyzed data for Study 2. MB, JL, MC, AJ, and KV wrote the manuscript.

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Measuring Counterintuitiveness in Supernatural Agent Dream Imagery

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The present article tests counterintuitiveness theory and methodology in relation to religious dream imagery using data on religious dream content. The endeavor adopts a "fractionated" or "piecemeal" approach where supernatural agent (SA) cognition is held to be a pivotal building block of purportedly religious dreaming. Such supernaturalistic conceptualizations manifest in a cognitive environment of dream simulation processes, threat detection, and violation of basic conceptual categorization characterized by counterintuitiveness. By addressing SA cognitions as constituents of allegedly religious dream imagery, additional theorizing and supporting data are presented in a growing body of research in the cognitive science of religion (e.g., Barrett et al., 2009; Hornbeck and Barrett, 2013; Barrett, 2017) and on religious dreaming (McNamara and Bulkeley, 2015; McNamara, 2016). The aim of the article is partly to map and align contemporary theorizing regarding counterintuitiveness and CI schemes with empirical qualification of the prosaic hypothesis about the predominance of supernaturalism in allegedly religious dreaming. This is done by (1) exploring the crucial topic of the pervasiveness of cognitive counterintuitiveness; (2) testing Barrett's counterintuitiveness coding and quantifying scheme (CI scheme) for counterintuitiveness in the context of religious dreaming by assessing intercoder reliability; and (3) exploring the prevalence and base rate frequency of counterintuitiveness in dream reports. This undertaking aims to contribute to the methodology and understanding of religious dream cognition, as well as to establish the cross-cultural base rates of counterintuitiveness in dreams for future research.

Keywords: dreaming, cognition, counterintuition, supernatural agent concept, religion, CI scheme

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INTRODUCTION

Supernatural agent concepts consistently appear in dreams in association with diminished agency in the dreamer (who thus loses individual agency and ego), which may facilitate supernatural agent cognitions related to religious beliefs. The anthropological and religious research literature tends to demonstrate that dreaming, dream experience and narratives found in traditional societies connect to other religious ideas and practices (e.g., Tylor, 1871; Lincoln, 1935; Tedlock, 1987; Jedrej and Shaw, 1992; Doniger and Bulkeley, 1993; Mageo, 2003; Lohmann, 2003a,b; Bulkeley, 2007, 2008; Laughlin, 2011). Based on analysis of lived and practiced folk-religion from various parts of the world, a notion has developed among scholars characterizing *dreaming as the primary source of religion*. Such a single "magic bullet" theory is ambiguous, however. A strong case can be made for the notion that supernaturalistic cognition prevails in dreaming processes connected to cultural environments rich in other religious representations. The aim here is to map a particular structure of cognitive content using Barrett's counterintuitiveness coding and quantifying scheme (CI scheme) in allegedly religious dreaming by focusing on supernatural agent imagery and concepts. Are these types of items in subjective dream reports a similar kind of catchy and peculiar content as has been demonstrated from the cultural transmission of other supernaturalistic notions and religious ideas generally? If it can be shown that allegedly religious dream imagery involves similar counterintuitive processing, this would help further explain why dreams cross-culturally tend to have a certain salience, and why these types of experiences and imagery are rendered special value and usefulness in cultural and religious institutions. From the perspective of the broader naturalistic research program of cognitive (and evolutionary) science of religion, many of the kinds of characteristics that occur in these dreams are *supernatural agent* (SA) concepts. The use of "superhuman" or "supernatural" agents (e.g., ancestors, gods, ghosts, sprits, souls, demons, saints, and even religious experts) is an indication that these notions hold at least an important, and perhaps a constitutive, position in religious beliefs and ritual action (c.f., McCauley and Lawson, 2002). Further, religious dreaming draws upon the same neurocognitive mechanisms as do ordinary dreaming and cognitive processing, as well as the cultural transmission biases that amplify and contextualize the spreading and preservation of representations about dreaming. It has been noted that, with some exceptions (e.g., Bulkeley, 2007; Nordin, 2011; McNamara and Bulkeley, 2015; McNamara, 2016), dreaming has not garnered much attention in the cognitive science of religion and related fields (c.f., Bulkeley, 2004, p. 22; Taves, 2008). While anthropological literature points to the cross-cultural pervasiveness of supernaturalism in dreams, and the cognitive science of religion has paid a lot of attention to the cognitive and or functional peculiarities of supernaturalism, there are very little cross-cultural data and research on the cognition of supernatural dreaming. Religious and supernatural agent dream imagery tends to be ritualized, and is awarded special (sacred) value and cultural institutionalization related to interpretive rationalization and *modus operandi*. But why should dreaming produce supernatural agent imagery? It has been suggested that this sort of imagery and related emotional activation are generated from evolved threat simulation processes during sleep (Bulkeley, 2007; Nordin, 2011). Such a system is perhaps part a grander evolved system for agent-related threat detection (Nordin, 2011) that has been described as the hypersensitive agent detection device or HADD (Barrett, 2004a,b; c.f., Guthrie, 1993) and is tied to theory of mind attribution. Such a model suggests that HADD and threat simulation make use of an increased inclination to simulate and detect agency in situations of urgency and uncertainty. Dreams and nightmares with salient content, strong negative emotions, and existential anxiety create urgent concern. Perhaps the sensed urgency in dreams would contribute to supernatural beliefs, since these concepts are particularly salient and inferentially rich (strategic knowledge and morality); and are usually already available in the believer's explanatory repertoire. And consequently, the intentions of extraordinary agents with extraordinary properties are likely to be believed to be the cause or content of the dream (Nordin, 2011). This may be the case because, according to HADD, salient dreams may be conceived as traces or communicative signs from other agents (Barrett, 2004a,b). However, supernatural agent dream imagery is often manifestly extraordinary in some way, and it is consequently not obvious that such imagery connects to inferences that imply a maximal potential for cognitive relevance.

On the other hand, why does the dream cognition start to represent extraordinary or counterintuitive properties? Neurocognitive theories further suggest that the combination of dream simulation, theory of mind attribution, and high dopaminergic/low serotonergic activation generates special (religious) value hierarchies (McNamara and Bulkeley, 2015; McNamara, 2016) in REM sleep at the same time as a significant deactivation of the prefrontal cortex occurs. Such states would seem to deplete the attributions of an agentic self-model being the cause of the dream events while at the same time exaggerating the salience of a sense of agency attributed to supernatural characters in the dream (McNamara and Bulkeley, 2015; McNamara, 2016).

Still, questions remain about why prediction or simulation would construct the dream items with extraordinary or counterintuitive properties. Whether when dreaming or awake, how and why are supernatural agent concepts and imagery given their peculiar cognitive properties? In the cognitive (and evolutionary) science of religion, SA concepts and cognition have gained a lot of attention and been theorized and researched according to the phenomena of counterintuitive processing and minimal counterintuitiveness (MCI) theory (e.g., Boyer, 2001; Barrett, 2004a,b). Minimally counterintuitive concepts violate certain intuitive assumptions about properties of categories such as agents, objects, and artifacts, rendering such concepts more salient, memorable, and inferentially rich, and consequently more likely to successfully achieve cultural transmission. Entities such as SAs can have either an overly excessive counterintuitive effect, making it difficult to remember characteristics and hence retrieve and communicate the concepts, or an overly weak counterintuitive effect, weakening the impression and hampering memorability. There is ample evidence of the prevalence of SAs in dreams from around the world and their constitutive relation to other "religious traits." Such supernaturalism suggests the operation of (minimally) counterintuitive processing. However, what if all dreams (even those not tied to other "religious traits") actually contain counterintuitive imagery processing as a subcategory of a general dream-symbolization (c.f., Brereton, 2000)? Might so-called "religious dreams" instead reflect a general tendency of cultural schemata and institutionalization to adopt certain recalled fragments from a broader pool of counterintuitive dream "stuff"? MCI theory seems to imply that not all catchy and attention-grabbing ideas are counterintuitive, but some are, notably those connected with religious traits that contain supernatural agent imagery.

These observations raise general concerns about (1) why dreaming should produce supernatural agent imagery, and specifically (2) why supernatural agent dream imagery presents itself as counterintuitive; and further (3) empirically, to what extent is religious and supernatural agent dream imagery actually counterintuitive? The purpose of this article is partly theoretical, dealing with the issue in (1) + (2), and in doing so offering empirical support for topic (3) by adopting and testing Barrett's methodology and coding scheme for counterintuitivity and its intercoder reliability. This is accomplished by examining reports from Hindu Nepalese respondents on the allegedly counterintuitive content in "religious dreaming." In particular, a report is offered on the prevalence, modalities, and types of counterintuitive dream imagery described by Hindu Nepalese respondents. This article presents interrelated strands of research related to dreaming, religion, and cognition, such as the neurocognition of dreams, anthropological research on supernatural dreaming, and models of supernatural agent cognition from the field of the cognitive science of religion. The discussion concludes by adopting and testing Barrett's coding scheme for counterintuitivity to explain and provide empirical support for the prevalence and modalities of counterintuitive dream content.

Dreaming in Anthropological and Religious Research

Anthropological analysis has suggested the notion that dreaming is the primary source of religion. This is recurrently observed in religious ideas and practices in traditional cultures (e.g., Tylor, 1871; Tedlock, 1987) and further implies that dreams are useful tools for spreading and transmitting religious ideas (Knafo and Glick, 2000). The early and classical accounts in Tylor suggested that dreaming was the experiential source of religious beliefs based on the observation of a nearly universal belief that dreams are experiences of, and communication with, "real" souls, spirits, ancestors, gods, and other supernatural entities (Tylor, 1871). These approaches suggest that it is likely that early human populations (and probably human populations ever since) deployed dreams as *evidence* for supernatural entities and realms, and such convictions drew upon the *vivid emotional experience*, sense of "realness," and *involuntary encounter* with others. Such evidence is cross-culturally manifested in "visitations" – dreams that combine an intense sense of realness with strongly apprehensive or non-apprehensive experience.

Anthropologists have contributed to the understanding of how cultural environments tend to emphasize different dream models concerned with themes of: "nonsense"/bizarreness; discernment; semiotic messages; generative precognition; "soul travel"; and visitation in dreams (Lohmann, 2007, pp. 41–44). Furthermore, the importance of the pragmatic and communicative context of the dream and the dreamer has been emphasized (Tedlock, 1987). Consequently, different discursive or explicit cultural models exist, and according to Kilborne, seven (overlapping) dream classification systems are common, based on how dreams are perceived, used, and connected to social dynamics and pragmatic concerns (Tedlock, 1987, p. 174). For example, dreams can have divinatory, political, religious, artistic, formal, therapeutic, psychodynamic, or expressive functions. These different uses of dreams illustrate the values attached to supernatural agent concepts and have been demonstrated in various ethnographic descriptions (e.g., Jedrej and Shaw, 1992; Peluso, 2004; Renne, 2004). However, these approaches and descriptions are slightly weak theoretically, and provide no information about the structure, content, and distribution of cognitive cultural schemas and scripts associated with religious dreaming.

The ethnographic literature points to the widespread cultural value attached to supernatural agent concepts and dreams (Jedrej and Shaw, 1992; Littlewood, 2004; Peluso, 2004; Renne, 2004) and their importance in all the world's religious traditions (Doniger and Bulkeley, 1993; Bulkeley, 2007, 2008, 2009). Studies of Taliban Jihadists (Edgar, 2004), independent churches in Nigeria (Renne, 2004), Trinidadian Baptists (Littlewood, 2004), and Jewish nationalism (Knafo and Glick, 2000) have noted the importance of religious dreams and the tendency to institutionalization. "The idea of certain status and value relates to the culturally widespread notion that dreams serve as anchors of belief conviction by offering direct experiential verification of religious entities and a spirit realm" (Bulkeley, 2008). Noteworthy results from cross-cultural ethnographic surveys of dreams highlight the importance of cultural traits that relate dreams to religious systems (D'Andrade, 1961). There is widespread use of dreams to contact or gain control of supernatural (agents) powers, and there are prevalent beliefs about the soul wandering during sleep and meeting other souls. D'Andrade's study shows that anxiety about being alone, demands of self-reliance, and isolation give rise to powerful preoccupations with supernatural dreams (D'Andrade, 1961. pp. 320, 328). It is often held that the dreamer's soul visits the spirit world and communes with gods and spirits (e.g., Lohmann, 2003a,b). Furthermore, in various cultures and religious traditions, dreams and nightmares are employed by shamans, healers, prophets, and oracles in local disciplines and rituals such as cults of pilgrimage, initiations, and conversion ordeals (Morinis, 1982; Bulkeley, 2007; Nordin, 2011). Nightmares are often held to be warnings from spirits, ancestors, God or the gods, or demons. Ethnographic accounts from various traditions in which ancestor worship is common practice also note that dead ancestors appear in frightening and memorable dreams to reprimand the dreamer for failing to perform commemorative rituals (e.g., Trompf, 1990; Jedrej and Shaw, 1992; Boyer, 2001).

Supernaturalism, Supernatural Agent Concepts, and the Category of "Religion"

From a cross-cultural and cognitive perspective, religious notions and supernaturalist imagery share recurrent features. Within the research program cognitive science of religion, minimal counterintuitiveness (MCI) theory was developed to explain the cognitive features and cultural transmission success of supernaturalistic representations. The prevalence of counterintuitiveness in supernaturalist and religious contexts has been amply demonstrated, while at the same time the general theory is under constant revision, through confrontation with empirical and ethnographical testing and debate.

A key question in this article is: to what extent do religious dream imagery and narratives contain counterintuitive properties of this sort, given the general predominance of supernaturalism in religious dreaming? This study starts from the methodological assumptions that the category of "religion" encompasses a broad range of phenomena that must be "fractionated" into constitutive parts. "Religion" is, anthropologically speaking, not a unitary phenomenon (e.g., Bloch, 2008; Boyer, 2013; Sperber, 2017) but a cluster of more basic and recurrent traits and cultural expressions that do not co-occur in every social environment. These elements – their recurrence and relationships – can then be addressed separately, making them more amenable to scientific investigation (e.g., Atran, 2002; Boyer, 2005; Sørensen, 2005). This is a kind of "piecemeal" (Barrett, 2007) or "building-blocks" (Taves, 2011) approach to the research area that explores targeted exemplars of cultural expressions that are seemingly related in cause or effect from the perspective of prominent explanatory models such as evolutionary cognitive and psychological accounts (regardless of any purported cultural or ideological systemization of the items).

Sleep States and Some Neurocognitive Correlates to (Religious) Dream Production

Dreaming is a universal human experience, but despite the mundane belief that dream content is mostly unintelligible and bizarre, research shows that it is structured in relation to activities, thought, and feelings from waking life (e.g., Hall and Van de Castle, 1966; Revonsuo, 2000a,b; Domhoff, 2003; Bulkeley, 2007). By dreams can be meant mental/emotional imagery and representations that occur during sleep. A dream can be defined as a subjective experience that occurs during sleep and consists of a temporal progression of images (c.f., Revonsuo, 2000a, p. 878). The literature points to various theories regarding the functions of dreaming (for an overview see Bulkeley, 1997; Revonsuo, 2000a). Neurocognitive models (e.g., Foulkes, 1985; Hobson, 1994; Solms, 1997) usually stress the randomness of dream imagery and the epiphenomenal and non-functional nature of dream *content* (c.f., Revonsuo, 2000a, p. 880). By contrast, psychological theories tend to regard dreams as a way for the individual to cope psychologically with the conditions of his/her current waking life and as promoting well-being (e.g., Jung, 1933). Dreaming is thus seen as serving as a means of solving intellectual or emotional problems and enabling use to adapt in order to cope with problems faced in waking life (e.g., Breger, 1967). Other research suggests that dreaming does not help provide solutions to problems in daily life (Blagrove, 1992), though this may not apply to religious folk models of dream function (and the alleged placebo effects of religious dreams).

Although most dreaming seems to occur during REM (rapid eye movement) sleep, the mind-brain system is active during the entire sleep cycle, indicating that we dream more or less all night long (Bulkeley, 2007), even during NREM (non-REM) sleep states (e.g., McNamara and Bulkeley, 2015).

Research by Hobson et al. (2000) demonstrates the complex and distinct quantitative variance between REM and NREM processing, and between REM and mentation during waking states. Some of these differences are manifested in the fact that affective and intensely emotional experiences are generally much stronger in REM than in NREM states (Hobson et al., 2000; Scarpelli et al., 2019). Additionally, Hobson et al. (2000) summarize physiological characteristics that differ between REM, NREM, and waking states: (1) during NREM nightmares, autonomic activation is higher than during REM night terrors; (2) despite the predominance of anxiety in the emotions of dreaming during REM sleep, the locus coeruleus region is inactive, even though that region is active during anxiety responses in the waking state connected with noradrenergic output; (3) the dream anxiety typical of REM sleep is likely to be underpinned by cholinergic activation in the limbic system, which may not be as prominently engaged in anxiety during waking states; (4) REM and NREM sleep states also discharge differing stimulus responses and cognitive processes, some of which will be further elaborated upon below. Alternatively, Kirov et al. (2012) consider the differences between the waking state, NREM sleep, and REM sleep to be about variance in connectivity, neuroelectric signaling, mentality, and neurochemistry. Further, Kirov et al. note that, under conditions of REM sleep, emotions emerge outside of a goal-directed behavioral context and with a lack of external input, and their conceptual and motivational schemata are opaque and vague during these states (Kirov et al., 2012).

The research literature on the neurobiological mechanisms of REM sleep regulation that produce dreams has highlighted the commonalities between the neural basis of REM sleep and emotional processing (overview Scarpelli et al., 2019). As shown in brain-imaging studies, there is augmented activity in brain regions such as the pontine tegmentum, thalamus and basal forebrain, the limbic and paralimbic structures during REM sleep, as compared to NREM sleep activities (e.g., Maquet et al., 2005) and waking states (e.g., Nofzinger et al., 1997). Other brain regions such as the dorsolateral PFC (dlPFC), precuneus, orbitofrontal cortex (OFC), and posterior cingulate gyrus are instead deactivated, compared to during waking states (e.g., Braun et al., 1997). These conditions may explain some of the transformed time perception, loss of executive functions, and the lack of insight that characterize dreams (Desseilles et al., 2011). Further, recurrent REM sleep features such as high vividness, bizarreness, and emotional load (e.g., Carr and Solomonova, 2018) that are salient during the dream experience also operate in cases of counterintuitive and supernatural agent dream cognition. This would be in line with the "continuity hypothesis" (e.g., Sterpenich et al., 2019), or with the suggestion that dreams and wakefulness share similar basic mechanisms. Consequently, during REM sleep and dreaming, most of the regions involved in emotional memory encoding are highly activated (e.g., Armony, 2013). This can be summarized as the emotional intensity of reported experience during REM sleep dreaming being explained by the higher activation of amygdaloid centers, the hippocampal formation, and the anterior cingulate cortex (ACC) during REM sleep states (e.g., Corsi-Cabrera et al., 2016).

Throughout the REM sleep period, several discrete physiological and neurological conditions occur. These include discharges in the autonomic nervous system, hormonal release, muscle paralysis and/or jolting, changes in blood pressure and heart rate, and high activation of the limbic region and the amygdala (detailed account in McNamara and Bulkeley, 2015; McNamara, 2016). In a summary by McNamara and Bulkeley (2015), during REM sleep, there is additional deactivation of the dorsolateral prefrontal cortex, the locus coeruleus, and the noradrenergic as well as the serotonergic systems, in addition to an activation of the dopaminergic and cholinergic circuits (also, e.g., Maquet et al., 1996; Hobson et al., 1998). The intricate co-occurrence of these brain activities during sleep states correlates with and may provide underpinnings for more higher level cognitive processes that generate supernatural agent concepts. There is a manifest difference, both in dream content and experience, between REM and NREM states, such that the former peak in negative emotions, nightmarish threat scenery, and bizarre imagery, while the latter manifest the opposite tendency (Hall and Van de Castle, 1966; Revonsuo, 2000a; Domhoff, 2003). It has been shown by McNamara et al. that scored aggression levels were lowest in NREM and wake reports, compared to REM sleep, and that imagery of friendliness signifies NREM states (McNamara et al., 2010). The correlation between apprehensive/non-apprehensive imagery and REM/NREM states respectively also suggests that the supernatural dream content is heavily affected. And indeed, various forms of aggressive, demonic, threatening, and predatory supernatural imagery prevail in REM states, while non-apprehensiveness, friendliness, and love characterize NREM imagery (Bulkeley, 2007; Nordin, 2011; McNamara and Bulkeley, 2015).

During dreams, the production of a self-model shifts or dissolves depending on neurological functioning, and a sense of involuntariness occurs, leading to the perception of other agents and entities as prime causal agents in, and of, the dream sequence. Consequently, a dream or sequence of dreams may be experienced as being caused by other agents, presumably supernatural ones, rather than the dreamer. These conditions manifest in alleged "religious delusions," where supernatural agents are held to be the cause of the patient's experience (McNamara and Bulkeley, 2015) such as manifested imagery of "demons" and evil spirits (McNamara and Bulkeley, 2015); indeed the lavishness of expression of religious delusions and abnormal experiences is more prevalent in patients with schizophrenia (e.g., Mohr et al., 2010) and sleep deprivation.

Overall, and as previously has been noted from cross-cultural accounts, supernatural agent dream cognition and imagery are common features of nightmares. Importantly, supernatural agent imagery is a common feature of extreme forms of terrifying nightmares manifested in sleep paralysis, incubus dreams, horrifying lucid dreams, and psychiatric disorders such as nocturnal panic attacks, all of which frequently arise during REM sleep (e.g., Nordin, 2011; McNamara et al., 2018). Even though these parasomnias may, like narcolepsy, be considered as sleep disorders in their own right, they are characteristically observed in a variety of psychiatric disorders, such as major depressive disorder, anxiety, post-traumatic stress disorder, attention-deficit/hyperactivity disorder, schizophrenia, bipolar disorder, borderline personality disorder, and other psychopathological conditions such as substance abuse (e.g., Kirov and Brand, 2014; de Sá and Mota-Rolim, 2016; Molendijk et al., 2017; McNamara et al., 2018; Tempesta et al., 2018; Baird et al., 2019).

Dreams are routinely forgotten, and only a few are preserved and conveyed to the waking state. On the other hand, certain types of dreams are memorable and are retained in memory and conscious awareness. Current cognitive research suggests that emotions influence many parts of cognition including memory (Slovic et al., 2007); hence emotions elicited in or by dreams are likely to influence whether and how dreams are remembered. Negative emotions are indeed common, and dream research suggests that 80% of dream reports refer to apprehensive experience (Hall and Van de Castle, 1966; Revonsuo, 2000a), of which fear is the most common, followed by anger and sadness. Other studies of dream reports demonstrate that 60% of *recurring* dreams and nightmares depict natural hazards or attacks by predatory or hostile beings (Robbins and Houshi, 1983). Being chased or attacked is also recurrent among those suffering from lifelong nightmares (Revonsuo, 2000a, p. 886). These recurring tendencies suggest that negative emotions such as anxiety, panic, and fear are important adaptive responses to situations in which reproductive fitness and survival are at stake (Marks and Nesse, 1994).

Simulation and Prediction in Dreaming

From evolutionary and neurocognitive perspectives, a parsimonious suggestion is that dreaming operates as way of exercising simulation and testing predicted or hypothetical outcomes. This would basically entail a presupposition about modality cognition and an ability to represent prospective and alternate counterfactual states of affairs (e.g., Lewis, 1973). However, in counterintuitive religious concepts, counterfactuality is disputed, and the notions should not be conflated (e.g., Barrett, 2004a,b; c.f., Atran and Norenzayan, 2004), though both may belong to a broader category also including bizarreness, etc. The existence of counterfactual dream simulation of past and future states has been demonstrated (McNamara et al., 2002) and extends to the state of REM dreaming as *prospective coding* (Llewellyn, 2016) and encoding for episodic memories (Llewellyn, 2013). For example, dreaming seems to be involved in the generation and development of future goals, values/desires, and contents of daydreaming in relation to *episodic prospection* (Spuznar, 2010; McNamara and Bulkeley, 2015) of possible states of affairs and outcomes. A prominent approach for explaining such types of dream machinery is *threat simulation theory* (Revonsuo, 2000a; Valli and Revonsuo, 2007, 2009). In this view, some dreaming processes seen during REM and even perhaps in NREM sleep are evolved cognitive processes selected for in ancestral human environments and geared to simulating threatening events and rehearsing threat perception and threat avoidance skills, so as to enhance vigilance to threats in waking life. Nightmares about *survival threats*, aggression, misfortune, and accidents are ubiquitous. Themes of "being attacked" or threatened by enemies, wild animals, strangers, or monstrous entities prevail in the majority of men's and women's dreams (Hall and Van de Castle, 1966; Domhoff, 1996).

Other adaptive simulation functions of dreaming have been suggested related to fitness pressures from costly social and sexual-selection signaling (McNamara, 2004), and simulation of social interaction (Brereton, 2000; c.f., Humphrey, 2000, pp. 953–953; Nielsen and Germain, 2000, pp. 978–979). Different versions of the "social simulation hypothesis"/"social mapping hypothesis" (Brereton, 2000) may be crucial in relation to social and sexual selection and partner choice. Furthermore, and more broadly, simulating scenarios about the intricacies of social life – intentions, interpersonal bonds, status competition, cooperation, alliances, trust, and so on – may improve social skills and have adaptive value (e.g., Franklin and Zyphur, 2005; c.f., Valli and Revonsuo, 2007, p. 113). Research on social perception and attribution of the theory of mind in dreams shows the significant amount of time dreamers spend pondering dream characters (Kahn and Hobson, 2005, pp. 48–57). Recent research indicates that REM sleep dreaming may serve other adaptive functions. For instance, neurobiological mechanisms and dreaming states during REM sleep may contradict the continuity hypothesis through incorporation, fragmentation, and reorganization of memories within dreams (Horton, 2017), a condition that suggests an enhancement of human heuristic inventiveness (Cai et al., 2009). Research also suggests that the occurrence of dreaming and REM sleep episodes operates as an adaptive interference, which integrates recurrent and recent memories into a broader vital context of the organism comprising emotions, basic needs, and individual genetic traits (Kirov, 2013). It has also recently been proposed that REM sleep dreaming could provide optimal conditions for the forming and updating of predictive coding, which will be further discussed in the next section (Hobson and Friston, 2012; Kirov, 2016).

Dream Simulation, Prediction and Cognition of Agency

Threat simulation theory connects to other cognitive proclivities such as a "hypersensitive agency detection device," HADD (Barrett, 2004a,b), and both may be instances of a general tendency of *precautionary psychology* (Boyer and Bergstrom, 2008). HADD refers to a composite cognitive mechanism responsible for the tendency to (over) attribute agency to phenomena in the environment, such as supernatural agents; the intuition of agency is rather spontaneous and automatic (Bargh, 1994), and activates seemingly innate systems for attributing and predicting intentions and motives of other agents, that is, the "theory of mind" or ToM (e.g., Leslie, et al., 2005). Theory of mind attribution has indeed been shown to be pervasive and dominant in dreams (Schweickert and Xi, 2010). Also, as aptly observed by McNamara and Bulkeley (2015), theory of mind attributions play a crucial role in modeling of supernatural agent cognition, for example as seen in the cognitive science of religion (e.g., Lawson, 2001; Barrett, 2004a,b, 2008). However, ToM attribution is not sufficient for providing a comprehensive characterization of religious dream imagery, and other dream properties may be crucial, such as a sense of peculiar value and reverence (McNamara and Bulkeley, 2015), or of strategically important information of cognitive relevance to the believer/dreamer (Boyer, 2001; Barrett, 2004a,b).

As indicated by the frequency of nightmares and apprehensive dreams, in REM sleep, the dreamers' agency is highly impeded or absent. Experiences that involve a suspended acting self-model may account for an increased sense of the causal agentive role attributed to other special dream characters (McNamara and Bulkeley, 2015; McNamara, 2016). According to a predictive coding approach (e.g., Howhy, 2013; Clark, 2016), cognitive brain processing, to grossly simplify, strives to confirm its own prospective states, actions, and thought. Experiences of being in charge of one's own actions, mental process, and sensory events derive from automatic and comparative processes between predicted and intended outcomes, such that if there is a match, the experience of self-causation increases, while a mismatch between prediction and actual outcomes encourages attribution of external causal agency (McNamara and Bulkeley, 2015). During REM dreaming, there is a downregulation of a self-model in relation to activation and intention, and hence a predictive gap. This may suggest that in dreaming, the mind simulates various counterfactual and possible scenarios, but the ascription of agency to ego-external agents results from unconscious responses to predictive failure and lack of sense of ego agency (McNamara and Bulkeley, 2015). These descriptions offer additional force to observations about people's proneness to dream agency attribution, though it does not completely explain why *supernatural* agency would be the preferred imaginary construct in religious dream episodes. According to McNamara and Bulkeley, the prerequisite for the production of highly memorable SA dreams is the same as that for the generation of ordinary SA concepts or God concepts, and involves mental simulation of alternate beings/realities, ToM attribution, and reckoning of extreme or ultimate values (McNamara and Bulkeley, 2015). This would suggest that all humans are bestowed with a mind-brain system innately primed to regularly generate supernatural agent concepts in dreaming. However, such a proposal raises questions about why not everyone's dreams contain SA images, whether non-believers' dreams contain these images, and to what extent devotees of any religious system have dreams filled with SA imagery.

Supernatural Agent Concepts and Minimal Counterintuitiveness Theory

The theory of counterintuitivity can partly be seen as an attempt to explain and model distinct recurrent features of supernatural or superhuman concepts. The core idea of minimal counterintuitiveness (MCI) theory is a notion of counterintuition that refers to violations, such as breaches and transfers, of intuitive expectations about basic ontological categories (e.g., Barrett, 2000, 2004a,b; Boyer, 1994, 2001; Pyysiäinen, 2001; and for a more comprehensive review of the literature, see, e.g., Barrett, 2008; Pyysiäinen, 2008; Purzycki and Willars, 2016). Such breaches and transfers hypothetically render (minimally) counterintuitive concepts *cognitively optimal* in cultural transmission and communication (Boyer and Ramble, 2001). MCI theory is concerned with why certain representations prevail and are catchier than others, and one prime cause of such catchiness seems to lie in how well they match our human conceptual systems rather than in the concepts themselves.

There is little doubt that human minds are better equipped to processes certain types of information and phenomena, such as social information, over others. Such a proclivity of "maturational natural cognition" (McCauley, 2011) ought to impact how concepts and ideas are recalled and consequently communicated and transmitted. This points to the fact that MCI theory is grounded in an epidemiological account of culture (Sperber, 1996). Cognitive processing that construes counterintuitive outcomes suggests that humans entertain intuitions – implicit expectations regarding what kinds of things exist and their properties. These are called *intuitive ontologies* that are spontaneously applied in *category formation* and in our everyday interaction with and understanding of the environment (e.g., Boyer, 1994, 2001). In consequence, humans utilize intuitive expectations and construe distinctions between entities such as animate and inanimate objects, and between persons, animals, plants, artifacts, and natural or physical objects. These descriptions are very much in line with, and based upon, the well-known description of two systems of cognition: intuitive, fast online processes, and slow, reflective off-line processes (e.g., Barrett, 1999, 2008; McCauley, 2011; Kahneman, 2012), and research on domain-specific cognition and categorization (e.g., Keil, 1989, 1992; Rosengren et al., 1991; Leslie, 1995; Gellman, 1999; Inagaki and Hatano, 2002; Spelke and Kinzler, 2007). Counterintuitive notions such as invisible beings, animate mountains, living stones, and statues that can cry or fly, are catchy, seize people's attention, and are memorable. By consequence, these items stand a greater chance of being communicated and selected over cognitively non-optimal concepts in cultural transmission. MCI theorists usually claim that cognitively optimal counterintuitive ideas form the backbone of significant traits in the cluster of religious phenomena and traditions, and explain the recurrence of certain types of concepts as resulting from cultural and cognitive selection. Still, MCI theory does not aim to account for religious concepts as making up some kind of naturally demarcated conceptual domain (e.g., Barrett, 2017). The original point was to account for why slightly counterintuitive concepts occur and endure between and within populations rather than maximally counterintuitive and perhaps many non-counterintuitive and bizarre concepts.

Numerous studies have tested and qualified the notion of counterintuitiveness by showing that modestly counterintuitive representations tend to be recalled and transmitted better than massively counterintuitive ones (Barrett and Nyhof, 2001; Boyer and Ramble, 2001); that once encoded, such MCI concepts are easier to retrieve than intuitive concepts; that the MCI effect seems to have a higher probability of impacting idea transmission among young adults and adolescents (Hornbeck and Barrett, 2013); and that contextual expectations and narrative embedding are crucial for the recall of modestly counterintuitive representations (Atran, 2002; Atran and Norenzayan, 2004; Gonce et al., 2006). This means that counterintuitive concepts are evaluated according to the contextual setting of which they are a part (Gonce et al., 2006). Other studies by Upal have suggested different types of minimally counterintuitive concepts based either on context-based models or on content (Upal, 2010). Research by Porubanova et al. suggests on the other hand that concepts that are culturally counter-schematic and unexpected are remembered better than concepts that violate ontological domain expectations (Porubanova et al., 2014). These studies show that notions of agents that breach both cultural-schema and domain-level expectations tend to be remembered better than concepts referring to object and artifacts (non-agents). The cultural transmission aspect of the MCI theory was also combined with other notions such as that of "inferential potential" and "strategic information" as an attractor and selection factor (Boyer, 2001, 2003).

The notion of "strategic information" suggests that any social information that would be relevant for and activate mental systems that regulate social interaction is strategic, under conditions where humans are incapable of having full access to all possible information of strategic bearing (Boyer, 2001, pp. 152–155). Strategic information need not refer to some ultimate importance or value, though the sense of urgency and importance probably derives from evolutionary and fitness-enhancing sensitivities (e.g., Nordin, 2015). Humans have imperfect access to all possible information of strategic relevance and consequently also to strategic information. People also seem to presume that others' access to strategic information is incomplete or concealed, with the exception of SA agents, which are commonly attributed counterintuitive properties.

METHODOLOGY

Quantifying Counterintuitiveness in (Religious) Dream Reports

In order to measure and quantify counterintuitive properties in religious representation, Barrett constructed a more precise procedure for specification, "Barrett's counterintuitiveness coding and quantifying scheme" – henceforth Barrett's CI scheme (Barrett, 2008) – which will be applied in the present case to supernatural dreams. Barrett's CI scheme enables predictions about the transmission advantage of score 1 counterintuitiveness. Any higher scoring counterintuitive breaches are likely to be re-represented in a simpler and less counterintuitive form. This may also suggest the occurrence of metonymic or metaphoric transfer of less counterintuitive representations. Coding and identifying counterintuitive concepts entails coding public representations (in our case speech acts of dream content) for their possible private representational structure (c.f., Sperber, 1996) and further, since it is likely that human minds generally strive for relevance and computational simplicity and efficiency (Sperber and Wilson, 1995), the coder should employ a *simplicity principle* regarding the way people conceptualize counterintuitive representations, and assume that the simplest and least counterintuitive concepts are employed (Barrett, 2008). The coding procedure involved the following six steps. First, we should identify the basic level category membership of the counterintuitive representation. Secondly, we should identify the ontological category(ies) of the allegedly counterintuitive representation, such as spatiality, physicality, biology, animacy, mentality (theory of mind), and universals. Thirdly, we should code the types of *transfers* of counterintuition as superscripts, with capitalized prefix; e.g., *Bhagawan* (Hindu God) manifesting as a gigantic stone pig speaking human language and offering advice and blessings is to be coded as "STATUE" (Biology + Mentality + Solid Object) = B(iology) + M(entality) STATUE. Fourthly, code any counterintuitive *breaches* of expectation as Superscript Lowercase Suffixes, e.g., *Invisible Mountain* (breaches of expectations of physicality). This item should be coded as Rock (or Mountain) = ROCK $^{p(hysicality)}$. If steps 3 and 4 (transfer and breaches) are combined, one may get such things as: *a growing and invisible statue* (transfer of expectation of Biology and breaches of expectations of Physicality), coded as Statue = $^{B(iology)}$ STATUE $^{p(hysicality)}$. There are further steps in Barrett's CI scheme, for example coding complex breaches, such as breaches within breaches, using parentheses. The final step of the scheme quantifies counterintuitiveness by totaling the number of symbolic letters, and provides a tool for robust quantification and specification of counterintuitive modalities in dream narratives, while the previous steps in the scheme provide rigorous criteria for the coding.

Research Questions

How common are counterintuitive properties in the context of allegedly religious dream contents? This article aims to (1) explore the topic of the pervasiveness of cognitive counterintuitiveness; (2) test Barrett's counterintuitiveness coding and quantifying scheme (CI scheme) for counterintuitiveness in the context of religious dreaming by assessing intercoder reliability; and (3) to explore the actual occurrence, prevalence, and base rate frequency of counterintuitiveness in dream reports. In order to map and measure the counterintuitive content, Barrett's CI scheme was employed and used according the following parameters: (1) degree of explication in terms of how manifest/implicit the counterintuitive content was in direct reports of dreams and in the dreamers' pondering about the nature of SAs that appeared in the dreams; (2) the number of counterintuitive object in dream reports; (3) the magnitude and scores of counterintuitive transfer and breaches; (4) types of CI objects (animals, artifacts, humans, others) and frequency of agent-based CI in relation to object-based CI. Using such parameters enables a phenomenologically more elaborate and fine-grained, and hopefully non-trivial, measurement of the modalities and prevalence of counterintuitive content in religious dreaming. In this context, the obvious and principal traits of counterintuitive content will be traced in order to demonstrate their constitutive function in religious dreaming.

Participants

The present study aimed to map the amount of counterintuitive content contained in purportedly strange dream reports and specifically religious dream imagery by means of interviews with mostly Hindu Nepalese informants in Nepal. Data were collected in central and western Nepal, in semi-urban and rural areas, but also around sacred sites such as temples (*mandir*), sites of pilgrimage (*tirtha*), and cremation precincts. A standard tactic for gaining the confidence and approval of prospective informants was to stay in a given public area for a while and unsystematically engage people in conversation leading to the question of whether they remembered any dream they had had. If so, prospective informants were asked whether they have had a strange dream or a dream where Bhagwan was seen. If the informant affirmed, this the interview would begin and last for approximately 1–2 h. Sixty participants were interviewed, of which 65% were male, and the mean age was 61 years (age range: 17–92 years).

Interview Format

The structured to semi-structured interviews followed a questionnaire that dealt with topics such as whether the informants remember any special or strange dream; what happened in the dream; if the dream content was communicated to others or if religious experts were consulted; whether they have had an explicitly supernatural dream (about "Bhagwan," "Devi," demons, etc.); whether they appreciated counterintuitive more than bizarre content; how they trusted and valued the dream content and attributed truth to it; an emotional dream score derived by measuring fear, joy, happiness, and various other parameters; and a score assessing religiosity. Informants were requested to reiterate a dream that came to their mind, then briefly ponder on what they thought that the dream was about, and whether it required moral and behavioral changes. The informants were further asked to spontaneously reflect on such topics as the properties of the supernal agents that appeared in their dreams. About halfway through the interview, informants were asked whether they had strange dreams that contained any seemingly strange items such as a "whispering stone" or a "weeping statue." The point was to cross-check whether the informants actually had manifest counterintuitive items in their narratives. As it happened, most informants had already mentioned some type of manifest counterintuitive items from their dream story, although some informants complemented their dream biography by confirming that they had had such strange dreams. This ensured that no obvious conformation effect, such as questions leading to statements from the informants that they otherwise would not have made, could be seen.

Most interviews were conducted by a field assistant and translator working with the Nepali- and Hindi-speaking informant. The standard English questionnaire needed translation into a Nepali version. The replies were retranslated into English for coding.

The Hindu Nepalese Ethnography of Religious Dreaming

Before applying Barrett's CI scheme, it is valuable to provide a realistic depiction about what is actually going on in these religious dreams and the content of the narrative context from which the dreams derive. A common way that informants indicated the presence of counterintuitive properties in their dream narratives was by means of phrases like: "*Shiva/Mahadev* appeared and advised me to conduct the puja"; "*Durga* came and made me wake up. Told me to take bath"; "I was sitting with *Bhagwan* somewhere in the mandir. Everyone was singing bhajan, and chanting mantra"; "*Bhagwan Pashupatinath* came in my dream and told me that the kind of life I was living must end." However, such frequent expressions are merely indirect clues of counterintuitive content, and not its manifest expression. Below are two examples demonstrating how and to what extent manifest counterintuitive content occurred in the supernatural dream narratives.

The first example of a dream narrative includes one counterintuitive transfer of mentality to an artifact or object coded as ^{M}**Artifact**, from the underscored section in the quote below:

> "Bhagwan appeared as a half statue (Murti)/half man offering advice"; "Bhagwan appeared as a statue talking to me like a human"; "a big snake (Nag) appeared whispering"; "I was sleeping in heaven in an abnormal flying bed in the air"; "an unknown/unseen voice came into my dream and ordered me to stop drinking alcohol and eating meat (to become vegetarian)"; "a Shaligram (fossil) came into my dream. It told me that I should stop people from doing business with Shaligram. It is a pabitra (sacred) work"; "I was sleeping in heaven in an abnormal flying bed in the air. Many Bhagwans (gods) were there around me worshiping me and throwing flowers to me."

The dream narrative in the second illustration comprises a number of counterintuitive properties such as breaches of universality in an artifact/object – **Bowl**^{u}; transfer to a person of the physical property of causing combustion – ^{P}**Agent**; and a breach where the dead come to life – ^{B}**Corpse**, as demonstrated in the underscored part of the quote below:

> "Among many dreams the dream that I like to talk most about is: Beggar wearing grey clothes who came to my house asking for rice/money. I went inside my house and took a bowl of rice from a basket and [poured it] … into his bag but the small bowl didn't empty. The bag was full and the bowl was also empty. I got surprised [went]…inside again, opened the basket, but it was full [of] … *Shaligram* (sacred ammonite fossils, usually believed to relics of, and animated by, the deity *Vishnu Narayan*) and flowers. I could see *mandirs* and rivers inside the basket where *Bhagwans* were singing and dancing. I went and joined [the] *Bhagwans* and *Devetas* there. I was like a friend to them. They put me on a bamboo stretcher and threw [me] into the water. My legs and body [were tied] with a *Nag* (supernatural serpent). I could do nothing after that; I was put on a block of firewood. Some unknown people (actually could not remember what is was) produced fire from the mouth and set fire to the firewood. I was burnt and died. The fire went out and again I got off the block of firewood and came down, nothing has happened to my body, I was surprised in the dream too."

RESULTS

In order to test and qualify Barrett's CI scheme, intercoder reliability was tested and then the scheme was applied to measure and quantify some core modalities of counterintuition in dream narratives.

Intercoder Reliability

First, regarding the general occurrence of CI objects in dream narratives, the agreement between the two coders was 95%. To statistically test the consistency between coders, Kendall's Tau-b was calculated. According to the statistical test, the intercoder reliability between the two coders was high and significant, $\tau = 0.875$, $p < 0.001$ ($N = 60$ counterintuitive objects). The three dream reports with disagreement regarding CI objects were in two cases due to both coders missing 1 CI object each, as well as one misidentification of an object by one coder; when this was pointed out, both coders agreed. This analysis concluded that 52 of the 60 dream reports had at least 1 CI element, and that the total number of CI objects in all dream reports was 57 (see **Figure 1**). The 57 CI objects were independently coded into 21 different categories and the intercoder correlation between coders was high, with a Cohen's Kappa of 0.88 (S.E. = 0.045, $p < 0.001$), which represent almost perfect agreement between the two coders. The dream reports that were in disagreement after the first coding were recoded into total agreement after a discussion. For example, in the case of a godly figure sitting on water, by appealing to norms about godly figures (they can sit on water) the coders decided that this object would be better coded as an Agent with a transfer of physicality than as Water with transfer of physicality. To further clarify, the disagreements were not so much about coding these figures as CI occurrences as about how to interpret a counterintuitive object in an ambiguous dream report; both coders agreed that if the dream report was interpreted in one way, the coding would have been in agreement. Overall, these results demonstrate the utility of the CI scheme for analyzing

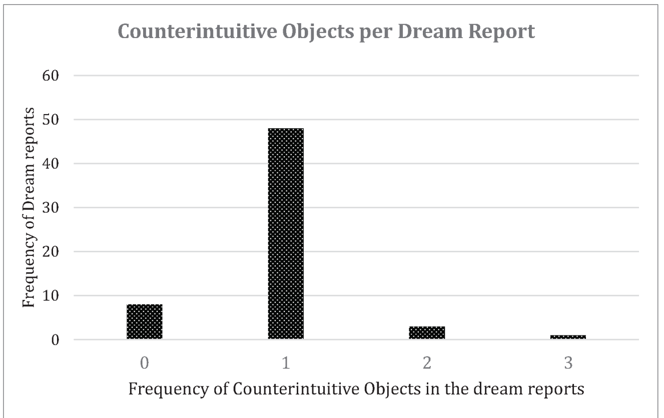

FIGURE 1 | Visualization of the distribution of counterintuitive objects within dream reports, most dreams have counterintuitive objects, further one counterintuitive object per dream report is most common, only a minority of dream report have two or three counterintuitive object.

dream reports, but also that using cultural schemas to interpret CI occurrences reduces ambivalence in dream reports. Hence, knowledge about both Barrett's CI scheme and normative beliefs about supernatural agents will improve intercoder reliability when coding dream reports.

Counterintuitive Objects per Dream Report

To investigate the frequency of counterintuitive objects per dream (Aim 1), we coded the number of CI objects that were reported per dream. Fifty-two of the 60 dream reports had at least one counterintuitive object (87%), suggesting that counterintuitive objects are relatively common in dreams, or alternatively that people remember or wish to communicate dreams with counterintuitive objects more than dreams without counterintuitive objects, which also would lead to a high frequency of dreams with counterintuitive objects being reported. Furthermore, in line with the theoretical suggestion that counterintuitive objects are related to cognitive load, 48 dream reports had one counterintuitive object, while only three dream reports had two counterintuitive objects, and one single dream report had three counterintuitive objects (see **Figure 1**). So, while counterintuitive objects occur in the majority of dream reports, making them frequent across dreams, they are relatively infrequent within dreams, with an absolute minority of dream reports having more than one counterintuitive object.

Counterintuitiveness Scores of Objects

Each counterintuitive object can theoretically have several breaches and transfers, or a combination of both. This is quantified by adopting the score of the sixth step in Barrett's CI scheme, where each breach or transfer gives the object an additional point. However, previous research on folktales suggests that most counterintuitive objects have a score of 1 (meaning they only have one breach or transfer) and that few counterintuitive objects have a higher score than 3. In line with these findings, the most common score in dream reports was 1. Specifically, 54 objects had a counterintuitive score of 1, three had a counterintuitive score of 2. There were no objects with a score higher than 2.

Most Frequent Types of Counterintuitive Objects

Most counterintuitive objects (47 out of 57) were agents, that is, objects that activated either mentality or animacy expectations or artifacts, humans, animals, substances, spirits, demigods, or gods with counterintuitive properties that acted intentionally in goal-directed ways. The most common agents in the dream reports were artifacts, often statues of gods that activated either mentality or animacy expectations (see **Figures 2, 3**). However, the second most common type of agents were bodiless voices (substance) that activated mentality expectations. Apart from these forms of counterintuitive objects with agent properties, a few cases (10 out of 57) consisted of counterintuitive objects with non-agent properties, such as impossible artifacts (e.g., a container that is larger on the inside than on the outside), luminous objects, etc. The prevalence of counterintuitive objects with agent properties may, at least according to the proposed byproduct and cognitive-relevance approach employed in this analysis, be explained according the principle that they entertain more cognitive routines and heuristics specialized on social information, interaction, inference, and utility in the least processing-costly way. This suggests that such proclivities predominate in the dreaming processes relating to imagery production, retrieval, recall, and communicative transmission. This supports Boyer's statement (Boyer, 2001) and Barrett et al. (2009) finding that in particular, counterintuitive intentional agent concepts obtain cultural transmission advantages over other sorts of counterintuitive concepts. The idea that intentional agent concepts should have transmission advantages derives from the theory of relevance (e.g., Wilson & Sperber, 1996), on which basis it is suggested that agent concepts have a more extensive inferential potential than other concepts, since they rely on a pervasive set of systems for social and moral interaction, and in the case of SA concepts, on strategic knowledge, etc.

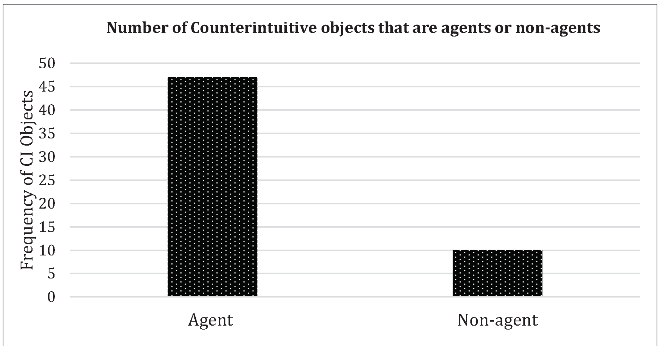

FIGURE 2 | The frequency of counterintuitive objects categorized into agents vs. non-agent, as seen in figure the majority of counterintuitive objects are agents.

DISCUSSION AND LIMITATIONS

Do so-called "religious dreaming" and SA imagery overproduce counterintuitive (below) imagery? Or do cultural and religious schemata provide an evaluative and conceptual context that enhances memorability and attention, and hence the selection and attraction of counterintuitive SA concepts? Although agent concepts predominate in dreams with counterintuitive contents, there are also cases of non-agentive counterintuitive dreams (below, empirical section).

Also, why should counterintuitive SA dreaming be limited to religious correlates? One common and general suggestion is that counterintuition, besides bringing strong and vivid emotions, improves the memorability, salience, and inferential potential of religious dreams, rendering these representations successful in cultural transmission and selection. Furthermore, the fact that certain cultural environments ascribe higher value to supernaturalist imagination and representations would indicate the operation of schemata that in themselves would support the memorability and transmission advantage of religious dreams.

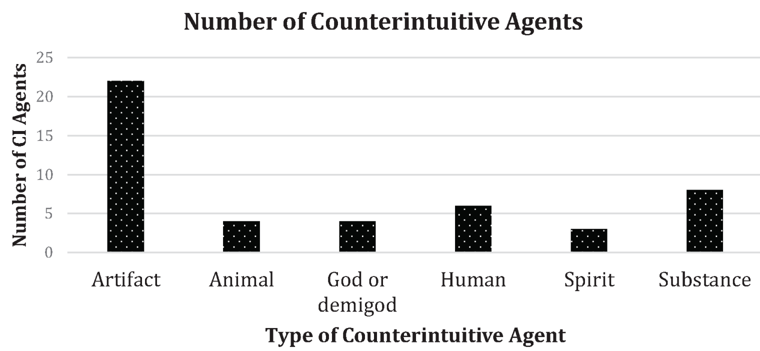

FIGURE 3 | The frequency of different types of agents in the dream reports, most of the agents in the dream report are artifacts.

The aim of the article was to map and align contemporary theorizing regarding CI schemes with empirical qualification of the prosaic hypothesis about the predominance of supernaturalism in allegedly religious dreaming. Our results suggest that exploring the pervasiveness of cognitive counterintuitiveness in dream reports is a promising way of merging theories about religious dreaming with MCI theories. They further suggest that Barrett's CI scheme is useful for coding counterintuitiveness in the context of religious dreaming. Lastly, we confirm that counterintuitiveness is extremely prevalent in dream reports. To our knowledge, this article is the first to apply Barrett's CI scheme to dream reports, and hence this undertaking contributes to the methodology and understanding of religious dream cognition as well as establishing cross-cultural base rates of counterintuitiveness in dreams for future research.

These conditions may be summarized according to a common model in the cognitive science of religion: just as the predisposition to detect and infer agency increases in situations of salient experience, urgency, and uncertainty (Barrett, 2004a, pp. 39–40), noteworthy dreams and nightmares with strong negative emotions and existential worry presuppose such a sense of urgency. Accordingly, stress from apprehensive experiences in dreams contributes to supernatural beliefs because: (1) supernatural agent concepts are particularly relevant, salient, and inferentially rich (strategic knowledge and morality); (2) they are usually already part of the believer's explanatory repertoire; and (3) they are culturally institutionalized as "special" cues that need interpretative decoding by experts and/or with manuals. In dreams, the supernatural agent concepts are particularly relevant and attractive to draw upon, and they outcompete other explanations. Accordingly, intentional actions by SAs with counterintuitive properties are likely to be held to be the cause or content of the dream. This would, according to HADD, be because salient dreams are conceived as traces of, or communicative signs from, other agents (Barrett, 2004a, pp. 36–37). However, previous accounts seem unable to explain why seemingly religious dreaming would (1) contain *manifest* supernatural agent imagery and (2) *manifest* counterintuitive properties of SA dream imagery in the first place.

Has the present study overestimated the amount of counterintuitive content in the dream reports? Major factors that could have led to overestimation, exaggeration, or distortion could be effects of various biases on the selection of informants, the interviews, the coding procedure, or the compilation and amalgamation of interview data. For example, Barrett et al. (2009) highlight that the distillation process in the collecting of folktales may overestimate the frequency of counterintuitiveness by combining oral versions into a written version, where such a compiled version would not operate under the same mnemonic limitations as verbal communication of narratives and stories. The present research tackles some of the methodological and conceptual challenges, such as issues about biased coding and data compilation. It demonstrates a slight discrepancy between the field assistant's and supervisor's identifications of allegedly counterintuitive traits in dream reports; however high agreement between the coders was registered, as previously demonstrated. General corroboration of the applicability of the CI scheme was given in Barrett et al. (2009), supporting the use of the strategy as common approach for identifying and quantifying counterintuitiveness. Another relevant and related topic that this article has not addressed is whether there is a cognitively optimum number of counterintuitive items in a reported dream narrative. Although the data point to instances where different counterintuitive items occur in a reported dream narrative, usually there is one counterintuitive item per dream narrative. This may agree with what Norenzayan et al. (2006) suggest as a base rate optimum for cultural transmission of sets of narratives as a whole. For example, it is likely that the transmission of oral material such as folktales and narratives selects for MCIs, while the cultural and institutional support for these items (Barrett et al., 2009) may increase the prevalence, magnitude, and extension of counterintuitive properties. The topic of a cultural transmission advantage or optimal number of counterintuitive representations in reported dream narratives may seem irrelevant for the actual occurrence of CI notions in dreams. However, there certainly is an intricate connection between the counterintuitive representations in a given cultural environment, their institutional and sacred value, asserted "specialness," religious "affordance" (c.f., Gibson, 1977), credibility enhancing potential (Henrich, 2009; Turpin et al., 2018), and the overt communicative exposure and priming effect they exert. Dreams are affected by and "situated" in social experiences, schemata, artifacts, and iconography developed and shaped in local cultural environments. The fact that counterintuitive contents in general, and counterintuitive intentional agent concepts in particular, are so predominant in the dream material from the interviews strongly suggests that this type of processing and information has a transmission advantage. It also offers some general support for cultural transmission models based on selection and attractor factors of evolved cognition and intuitions (e.g., Sperber and Hirschfeld, 2004; Claidiére and Sperber, 2007; Morin, 2016), even if these approaches are broad in scope and not aimed at explaining why CI imagery occurs to begin with.

Most dreams are routinely forgotten and only a few are selectively conveyed to the waking state. Some are sufficiently memorable to be retained in an individual's memory and conscious awareness. Religious or supernatural dream cognition seems to be highly effective in generating memorable experiences, because it includes supernatural agent concepts that are counterintuitive, and thus highly likely to be preserved in memory and further culturally transmitted (Nordin, 2011). This would explain the high frequency of CI in the dream reports. Consequently, the theory of counterintuitive processing – in combination with a readiness to attend to strategic information, cognition of contagion and essentialist reasoning related to the magical and ritualistic use of SA agents, and their cultural schematization and institutionalization – perhaps contributes to a fuller picture of the dream and culture interface.

As a final note, because dreams and dreaming are understood differently within different research fields (neurology, psychology, and anthropology), different research methods will be needed to capture dreams and dreaming. What constitutes a "true sample" of dreams might also differ between research fields. The theories on which we base our research state that dream research respondents are more likely to remember, and also transmit, dreams that contain CI. In light of this, our sample will be biased toward dreams with CI content. From one perspective, this is a limitation; however, it is also exactly what we expected and serves as confirmation of our hypothesis and the theories that it rests upon. However, to remedy this respondent bias, it is advisable to try to assess dreams that normally would not be communicated. There are reasons to believe that respondents do not generally report mundane or boring dreams, and because memory is a living process, these dreams will be forgotten. Instructing respondents to write down every dream they have during a week, even the most mundane dreams, should, in accordance with our thinking, produce a lower rate of CI in those dream reports. However, this might not fully correct the respondent bias, because memories of dreams are very fleeting, and dreams can be forgotten in the very instant when they are remembered. Further, an assessment like this would be different from what we tried to assess in our study. Our goal was to assess dreams that are remembered automatically and communicated freely, as these are the kinds of dreams that best represent what constitutes dreams within a culture.

CONCLUSION

The MCI model has been one viable area of research and debate in the cognitive and evolutionary study of religion. An issue that these scholarly debates and enquiries highlight is to what extent counterintuitiveness is a robust phenomenon and a recurrent feature of significance in the culturally variable repertory of supernatural agent beliefs. Other issues concern topics such as seemingly "non-religious" counterintuition, memory, the interface with bizarreness and counterintuitiveness, cultural schemas, and other transmission biases. Counterintuitiveness has been analyzed and confirmed in different cultural and religious contexts, though not systematically in the context of religious dream content. On the other hand, as has been demonstrated in this article, supernaturalism in dreaming has indeed been reported from many contexts and sources. The present article has offered support for the applicability of Barrett's CI scheme and MCI theory in explaining the crucial traits of SA and religious dreaming by measuring pivotal quantities and modalities of counterintuitive content. Employing a standard assessment of counterintuitiveness minimizes inter-study variability while improving comparability and base rates, and advancing the empirical exploration of MCI theory and comparable theories related to SA and counterintuitive concepts. Importantly, this article has demonstrated the prevalence of counterintuition in (religious) dreaming by quantifying a selected array of modalities that serve as markers of counterintuitive processing by applying Barrett's CI scheme and testing its methodological validity and efficacy.

DATA AVAILABILITY

All datasets generated for this study are included in the manuscript and/or the supplementary files.

ETHICS STATEMENT

- This research fully complies with the ethical guidelines of the Swedish Research Council, including with regard to informed consent, strategies of anonymization, and informing the interviewees about the consequences of their participation. All reasonable efforts were made to ensure that the ethnographic interviews and research process would not jeopardize participants' integrity. By following these conditions, the study avoided potential ethical problems from the start.
- Before each ethnographic interview, potential participants were informed about the consequences of their participation and told that they were contributing to scientific research on dreaming and the Hindu religion. It was made clear to them that they were free (1) to choose whether to take part in the interview, (2) to decline to answer any question, and (3) to stop the interview at any stage. Furthermore, they were fully informed that personal and sensitive topics were not part of the questionnaire and were not of interest for the research project. Interviewees gave their verbal informed consent, and strategies for anonymization were used.

- No vulnerable populations were involved. Regarding our choice of verbal informed consent, the use of written informed consent from informants is not practiced (in the social sciences) when ethical concerns are estimated to be largely absent and the procedures adhere to the guidelines of the Swedish Research Council. Regarding ethical approval, when research projects include topics of sensitive ethical nature, they must be approved by a committee at the local university in Sweden; however, the present project never touched on or dealt with such questions.
- As a consequence of the above-mentioned facts, ethical approval was not required as per the applicable institutional and national guidelines and regulations in Sweden.
- Finally, the present study was conducted in the developing country of Nepal, where seeking written informed consent would have been difficult, impractical, and even potentially counterproductive from an ethical perspective. This is because many persons in this sociocultural context may believe that signing formal (and foreign) documents could lead to legal problems and trouble with the authorities.

AUTHOR CONTRIBUTIONS

AN is the main author that with the aid of a field assistant collected data in Nepal. PB is co-author and worked with data collection strategy and data analysis.

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GENERAL COMMENTARY
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Commentary: Measuring Counterintuitiveness in Supernatural Agent Dream Imagery

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Keywords: dreaming, cognition, counterintuition, supernatural agent concept, CI scheme, complexity drops, unexpectedness, continuity hypothesis

A Commentary on

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Nordin and Bjälkebring's research on counterintuitiveness (CI) in the dreams of Nepali Hindus is seemingly the first case of applying Barrett's (2008) coding scheme to dream reports. This commentary briefly addresses Nordin and Bjälkebring's main findings with the coding scheme before considering their proposal for the manifestation of supernatural agents (SAs) in dreams. As discussed below, their proposal is vague and ignores other factors that are relevant to oneiric SA manifestation.

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COUNTERINTUITIVE OBJECTS IN DREAMS

According to Barrett (2008, 2011), whose work grounds Nordin and Bjälkebring's empirical study, humans naturally develop five general object categories/domains. CI applies to objects with properties that defy basic expectations for its domain (Barrett, 2008, 2011; Purzycki and Willard, 2015). "Talking tree" and "invisible statue that cries" meet CI qualifications because they defy basic expectations for plant and artifact domains. According to Barrett's (2008) coding scheme, these examples have respective CI scores of 1 and 2, given the number of violated expectations per domain.

Using the aforementioned coding scheme on a selection of Hindu supernatural/religious dream reports, Nordin and Bjälkebring report the vast majority of counterintuitive objects in their sample had a CI score of 1. This is consistent with expectations of minimal counterintuitiveness theory concerning cognitive load and narrative transmission (Barrett, 2008; Barrett et al., 2009). Additionally, they found just one counterintuitive object in the majority of dream reports, and counterintuitive agents greatly outnumbered other types of counterintuitive objects in their sample. Altogether, these findings are generally consistent with Barrett et al.'s (2009) study of folktales. The latter employed the CI scheme on an international sample and found artifacts possessing agent properties to be relatively rare. In contrast, artifacts were the most frequent counterintuitive agent in Nordin and Bjälkebring's study. A plausible way of accounting for this difference would be to consider the culture of Nordin and Bjälkebring's subjects. Idols (*murti*) are quite common in the villages and cities of Nepal, and a prominent part of Hindu religious life in particular. Thus, in association with the continuity hypothesis (see e.g., Domhoff, 1996; Bulkeley, 2009), I propose the frequency of counterintuitive object types in a dream report sample is a function of waking circumstances. Hence, a Christian or Muslim sample should reveal a lower frequency of counterintuitive artifacts than a Hindu one.

SUPERNATURAL AGENT COGNITION

Following McNamara and Bulkeley (2015), Nordin and Bjälkebring argue that the physiology of dreaming entails a diminished sense of personal agency, which could undergird SA cognition in light of the self's corresponding search for extrinsic event causes. Why, however, would subjects interact with SA concepts rather than other non-self concepts during dreaming? Nordin and Bjälkebring argue that certain situations the dreamer faces, viz., those involving perceived threat or anxiety, create inferential demands that make SA concepts attractive because of the latter's association with strategic information. While I would not want to discount their proposal entirely, several important concepts (threat, anxiety, strategic information) are vaguely defined, and other factors related to SA manifestation are ignored.

To support these contentions, I will briefly consider Nordin and Bjälkebring's second dream report example (p. 9). Though Nordin and Bjälkebring's theory applies to dreams rather than dream reports, the latter may nonetheless indicate features of the oneiric experience. Based on the report's details and Nordin and Bjälkebring's generic usage of threat and anxiety terminology, I am unable to conclude that the dreamer experienced these prior to the appearance of SAs. The dreamer's situation is more obviously a case of "unexpectedness" following a domain violation (involving a bowl). The concept of unexpectedness is lacking in Nordin and Bjälkebring's discussion, but it features prominently in several researchers' portrayals of religious/supernatural cognition (e.g., Taves, 2009; Hermans, 2015; Sears, 2016, in press). According to Fortier and Kim (2017), unexpectedness (resulting from drops in algorithmic complexity between expected and actual circumstances) begets agency detection, which leads to SA cognition if naturalistic concepts fail to account. Their "complexity drop model of the supernatural" (CDMS) arguably applies to the example under consideration[1].

[1]Readers of Fortier and Kim's essay will see that they associate complexity drops with domain-general (prototypical) violations rather than the domain-specific (ontological/basic) violations associated with counterintuitiveness in the technical sense (cf. Purzycki and Willard, 2015). They do not defend this division adequately, and I do not think it can be maintained, given that "atypical" objects occasion complexity drops (cf. Dessalles, 2007; Fortier and Kim, 2017, p. 287). Phenomenologically speaking, both types of violations generally create unexpectedness; furthermore, both types of violations have been linked to SA cognition (Fortier and Kim, 2017).

Nordin and Bjälkebring's threat theory and the CDMS explain SA concept activation rather than the visual experience of SAs. The latter is dependent on the former but requires special circumstances. From the perspective of hierarchical predictive coding, sensory data essentially acts as a corrective to mental modeling of perception (Hobson and Friston, 2012; Clark, 2013; Andersen et al., 2014). Based on this perspective, Hobson and Friston (2012) suggest the "bizarre" content of dreams may be due to sensory gating that normally occurs when the body is asleep. Following their reasoning, once SA cognition is activated during dreaming, subjects may continue to envision SAs without their appearance being impeded by sensory information (Sears, in press).

In sum, Nordin and Bjälkebrings's description of oneiric SA cognition is vague and limited. Besides diminished personal agency and threat/anxiety, unexpectedness, and sensory gating/deprivation play important roles in at least some SA dreams. Other factors—such as "ideal" content situations (Sears, 2016)—may likewise be relevant. Interestingly, each of the foregoing factors mentioned with respect to oneiric SA cognition has precedence in treatments of waking SA cognition (cf. Barrett, 2004, 2011; Taves, 2009; Andersen et al., 2014; Fortier and Kim, 2017). This statement is a testament to the principle of continuity between waking and dreaming. Given the typical physiology of dreaming, supernatural cognition and visual SA manifestation may be generally more common during dreaming than waking, though such possibilities stand in need of further research.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Response: Commentary: Measuring Counterintuitiveness in Supernatural Agent Dream Imagery

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Keywords: dreaming, cognition, counterintuition, supernatural agent concept, religion, CI scheme

A Commentary on

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(Sears, 2019) comment partly addresses the main purpose of our article (Nordin and Bjälkebring, 2019) about counterintuitiveness in dreaming. While we recognize that his remarks include some constructive points about the presented research results and highlight some possible limitations in the theoretical summary and modeling of supernatural agent (SA) cognition in dreaming, we take issue with other points and with the way our arguments are framed. In this response, we suggest that, given the prominent research in the field, parts of Sears's comment are overly dismissive and neglect to take into account key aspects of our specific arguments and our modeling of SA cognition in dreaming.

SEARS ON COUNTERINTUITIVE OBJECTS IN DREAMS

Sears offers a brief and partly constructive depiction of the empirical study described in the article. Some of our main arguments and aims, however, despite comprising the most significant part of the contribution, are omitted or only vaguely discussed. These include to measure the general pervasiveness of counterintuitiveness, to test (Barrett, 2008) counterintuitiveness coding and quantifying scheme in the context of religious dreaming by assessing intercoder reliability, and to explore the prevalence and base-rate frequency of counterintuitiveness in dream reports, and thereby establish cross-cultural base rates of counterintuitiveness in dreams for future research.

We agree with Sears's comments on our results about supernatural artifacts in dreams, on "cultural influences," and on the continuity hypothesis [see, e.g., (Domhoff, 1996; Bulkeley, 2009)]. The dreams undoubtedly draw material from and make reference to daytime experience and take cues from the cultural environment, which in the context of the present study includes Hindu imagery, "iconography," local worship, mythology, and visual culture. Sears's comment leads to welcome and constructive suggestions for future (cross-cultural) research: for instance, the prediction that a Christian or Muslim sample should reveal a lower frequency of counterintuitive artifacts than a Hindu one.

SEARS ON OUR MODEL OF SUPERNATURAL AGENT COGNITION

In the article, we refer to various studies (McNamara and Bulkeley, 2015; McNamara, 2016; McNamara et al., 2018) that stress the prevalence of co-occurrence of a diminished sense of personal agency and a tendency to construct SA cognition during rapid eye movement (REM) sleep. One possible explanation of this that we discuss is the hypothesis that dreamers produce SA cognition about agency in searching for extrinsic event causes during REM sleep (references above). We share Sears's questions about why this would be the case, and future research will probably offer a more complete answer. As we state in the article, there are strong *prima facie* reasons to suggest that, in this dream context, the ascription of agency, agent causality, and mentality is partly due to a proclivity to adopt a Theory of Mind (ToM), and that this occurs in a manner theorized as hypersensitive agent detection (HADD). We also discuss various "mind prediction" models (p. 6). We too think it remains unclear why, as McNamara et al. (2018) put it, "anyone would postulate SAs in the first place" given these processes, and even more to the point, why SAs should be counterintuitive.

Sears holds that our article employs important yet vaguely defined concepts such as "threat," "anxiety," and "strategic information." The importance Sears imputes to these concepts is somewhat exaggerated, particularly in relation to the limited space of the given article. Contrary to Sears's claim, the notion of "strategic information" is in fact described on page 7 and that of "threat" on page 5.

Furthermore, "threat" and "anxiety" were mentioned due to their functions in some of the prominent models to which we refer as theoretical background conditions for the generation of SA dreams. The empirical aims of the article, however, were (a) to map the prevalence of counterintuitiveness in dreaming, given how much attention minimal counterintuitive (MCI) theory has earned in the scholarly debate and (b) to test (Barrett, 2008) counterintuitiveness coding system. The aim was not to test any functions of "threat" and "anxiety" in the production of SA dreaming. Despite this, Sears contends that we are unable to demonstrate that dreamers experience threat and anxiety prior to the appearance of SAs. This seems to us like an irrelevant objection if it is meant as an attempt to refute our arguments and results. It also goes further astray by suggesting that we should adopt another theoretical framework altogether (seemingly Sears's own). We certainly welcome new explanatory theories if they are relevant and demonstrate parsimony. However, we are not unaware of, much less do we ignore, as Sears seems to imply, the notion of unexpectedness and the kinds of concepts he obviously favors and advocates. Nor do we dispute the viability of unexpectedness as a scientific concept derived from various "mind prediction" approaches; in fact, we discuss precisely these processes on page 6 in the article. We find it not altogether relevant, fair, or reasonable to dismiss our arguments and results about counterintuitiveness in dreaming on the basis that some other concept ought to have been used instead.

In sum, Sears's remarks offer some constructive suggestions and discussion, but we take issue with the overly dismissive comments on the article. We consider the criticism of vagueness to be exaggerated, while the criticism that we lack evidence of threat/anxiety in the empirical data is simply irrelevant, given the aim of the article. The charge of the article's limited value also has low credibility, even from the commenter's point of view, because (a) references to our most important concepts and to the entire research field of MCI and counterintuitiveness are omitted from Sears's criteria; (b) it overestimates *a priori* the explanatory value of other less well-established concepts in the field; and (c) it wrongly suggests that the article lacks any description of "unexpectedness"-type phenomena, when in fact it does describe them. Further, the charge of limited value is arbitrary and self-defeating as it presumes that "sensory gating/deprivation plays important roles in at least some SA dreams"—a statement that both begs the question and invalidates its own claim because its scope is limited by the qualification "in *at least some* SA dreams." We similarly find the assertion that our study is of limited value because we omitted the commenter's own stance—on "ideal" content situations (Sears, 2016)—to be rather question-begging and even biased.

AUTHOR CONTRIBUTIONS

AN authored this response to Dr. Sears's comment on the article Commentary: Measuring Counterintuitiveness in Supernatural Agent Dream Imagery. PB contributed to with comments and suggestions on the response.

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A Hypothesis About Parallelism vs. Seriality in Dreams

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The process of dream building implies the construction of a complex network of closely interrelated sources. On the other hand, the dream experience develops as a succession of events. In this paper a hypothesis is advanced about how the psychophysiological system of dream building, which is distributed, acts to provide a serial output. This hypothesis is basically connected with the property, enjoyed by the dream experience, of simultaneously representing a plurality of meanings.

Most of the products of our brain, which consists in an enormous number of cells and of interconnections among them, give serial outputs. In fact, physiological and psychophysiological systems generally interact serially with the environment, as is obvious with regard to, e.g., locomotion, reaching and grasping, and language. Two trivial examples are walking (we move a leg after the other) and speaking (we pronounce a word after the other). Seriality also appears to characterize the control of logical reasoning and, very generally, the flow of consciousness. In the vast literature about the issue of brain parallelism with serial output, a particularly significant role has been played in the last decade by the hypothesis of a Global Neuronal Workspace (GNW). According to a review by Dehaene and Changeux (2011), the GNW interconnects specialized, automatic and unconscious processors and, at the same time, is able to encode conscious contents by means of the sustained activity of a fraction of its neurons, the others being inhibited. The pattern of parallel computation with serial output is thus closely connected with the theoretical modeling of consciousness. In fact, quoting (Baars et al., 2013),

> "the capacity of consciousness at any given moment seems limited to one consistent scene. The flow of such scenes is serial, in contrast with the massive parallelism of the brain as observed directly."

A number of studies have also dealt with this issue in the framework of complexity theories, thus involving concepts of self-organization and emergent properties in cooperative dynamics (see, e.g., Werner, 2012; Allegrini et al., 2013, 2015; Paradisi et al., 2013; Paradisi and Allegrini, 2017).

As to dreaming, a fundamental property of this activity is that of making connections (see, e.g., Hartmann, 2010). The memory sources of a dream generally refer to recent or remote events in the dreamer's life, including significant "present concerns." The sources exhibit a network pattern that can qualitatively and quantitatively be described by an appropriate graph representation (Barcaro and Carboncini, 2018). To tackle the issue of how a serial output is obtained as a result of a distributed process, our reflections rely on four phenomena that characterize the network pattern (Barcaro et al., 2016):

1. "Pervasive links" exist, i.e., semantic links among sources that are related to a plurality of sources;
2. A heuristic rule can account for the construction of these links: they are such that the dreamer's present concerns are made less negative or even reversed into positive;
3. After an initially identified present concern, a second more important one can be recognized (this phenomenon has been called "shift of the present concern");
4. The dream experience fulfills a "representative function": the overcoming of negative contents is actually represented in the dream.

The first three phenomena are connected with the parallelism of the dream-building system, while the fourth is connected with the seriality of the output.

As to point (2), the heuristic rule closely resembles the Freudian theory of wish fulfillment. However, the literature data that we have considered do not precisely refer to the Freudian Unconscious and do not imply that the rule is valid in all cases.

Our point is that the serial output is created by the system in a conceptually simple way, i.e., by providing a dream plot able to simultaneously represent the overcoming of the present concerns, which are more than one because of the shift of the present concern. This property appears as a typical feature of the dreaming experience.

THREE EXAMPLES

To illustrate our point of view we briefly discuss three examples. The rationale for the analysis of dreams consists in observing that (Barcaro et al., 2016):

a) The presence of a non-serial network of dream sources shows that the dream-building system works in a distributed way;
b) More than one present concern is at the basis of the building of the dream;
c) The serial output, i.e., the dream experience, allows the overcoming of the present concerns to be represented simultaneously.

Analyses similar to those carried out for the examples can be performed considering many other dreams that have been reported in the literature, which offers a large amount of dream reports together with associations (see, e.g., Delaney, 1993; Barcaro et al., 2016).

(i) The Dream with the house in the courtyard (25-year-old woman, Barcaro et al., 2005):

After being awakened in the morning, the dreamer reported of finding herself inside a house in a courtyard, during a cold night, with other people. After leaving the house they came back and entered another room. Finally, they left the house. In the associations, the other people were immediately identified as her parents and grandparents. The links among the sources provided a closely interconnected pattern, including four pervasive links; for the details of this pattern, we refer to the article from which this example has been taken. The dreamer immediately associated the cold of the night with a feeling of extreme sadness and this feeling with her grandfather's illness. She later indicated a further, very different, present concern, due to her opposition to coming back to the house where they had lived during her adolescence: indeed, her grandfather was the one who most insisted on coming back. Although the feelings related to these two concerns were different and somehow opposite with regard to her grandfather, the serial dream experience managed to represent both feelings, i.e., sadness and desire of definitely leaving that house.

An interesting detail of the dream experience is that, after leaving the house, they entered again and left it again: this well corresponds to the waking-life concern about coming back to the old house.

(ii) The Dream with a doctor wearing a white coat (46-year-old woman, Barcaro et al., 2016):

The dreamer reported of being in a hotel room where a doctor with a white coat was visiting her. At the end of the dream, she was skating fast in the room along the spaces among the beds. The associations identified numerous sources and links among sources. The dreamer indicated two present concerns: the wish of improving her relationship with her daughter, and the need to overcome a temporary difficulty in moving. The white coat was the one that her daughter wore in her school lab. The idea of skating was connected with important events in the dreamer's life: her mother had taught her how to skate when she was a child; she had often skated pleasantly together with a partner with whom she had made interesting journeys. Interestingly, the event of skating with that partner was recollected very lately in the course of the associations. The serial dream experience fulfilled a complex representative function: she completely recovered, she was able to relive pleasant experiences of journeys and physical exercise, and she found a tender help on the part of her daughter. The beds in the dream provided a setting able to simultaneously represent a hotel, a medical office, and a skating rink, given by the spaces among the beds.

(iii) The Dream with the evil tortilla (2.5-year-old child, Siegel and Bulkeley, 1998):

The small child dreamed of being attacked by an evil tortilla that was trying to smother her. She had always enjoyed eating burritos; recently, she and her older sister had invented the funny play of wrapping themselves inside a blanket, thus pretending to be part of a burrito. On the day before the dream night, the dreamer had suffered a mild burn from touching a tortilla too soon after it had emerged from the toast oven. Thus, the idea of burrito/tortilla provides a pervasive link. **Figure 1** shows the graph representation of the link pattern among the sources, which is very simple in this case because of the presence of only one pervasive link. The concern about the burritos possibly being harmful was reversed through the association with a pleasant game. The dream experience simultaneously allowed her to overcome the concern due to the burning experience, to avoid interrupting the funny play, and to recover her trust on burritos. Certainly, she was frightened by the dream, in the same way as she had being frightened while being burned. However, a basic point is that the evil tortilla only attempted to smother her.

Similar mechanisms can also be observed in dreams of famous people that have been reported in historical documents. For instance, at the age of 29, Charles Darwin dreamed of a corpse coming back to life after being executed (for a discussion about this dream, see Bulkeley, 2016). Clearly, a serious present concern in the dreamer's mind was due to the establishment's opposition to his theory. The dream experience represented the idea that the unjustly accused theory was able to come back to life. Thus, the dream experience presented a somehow ironically reversed form of the Christian dogma of Resurrection.

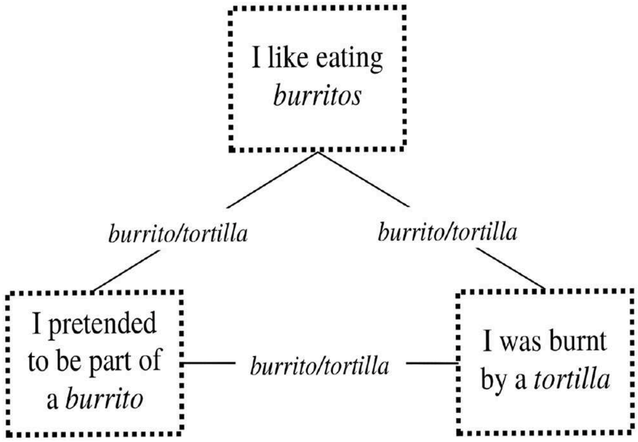

FIGURE 1 | The graph representing the link pattern between the sources of the Dream with the even tortilla is very simple, consisting in a triangle. The nodes are given by the three sources, each pair of which is connected by the pervasive link "burrito/tortilla," which thus provides the three arcs connecting the nodes.

SHORT DISCUSSION

We now briefly consider the here proposed hypothesis from the points of view of the continuity theory, the plurality of dream meanings, and the respective role of conscious and unconscious items in dreams. The continuity theory states that close continuity exists between dreaming and waking life (see, e.g., Nielsen et al., 2004; Blagrove et al., 2011; Hobson and Schredl, 2011; Domhoff, 2017; Schredl, 2017). In particular, dream contents appear to be connected with important events in waking life (see, e.g., Perogamvros et al., 2013). The continuity theory has had many experimental confirmations and has often led to enlightening results about the process of dream building. In our case, the connection between recent and/or remote events in the real life is at the basis of the construction of the link patterns between sources, and the representative value of the dream experience is directly related to waking experiences. As we have observed in the above examples, elements of similarity between dream events and waking events are sometimes striking. The serial output offered by dreams simultaneously represent more than a single content, even though the contents can present contradictory aspects. This plurality of meanings maintains a trace of the distributed character of the dream-building system in the serial output. Certainly, a simple interpretation of a dream can often be obtained if a present concern is well known by the interpreter (who can be the dreamer himself or herself). However, because of the plurality of meanings of the dream experience, a simple interpretation, based on an arbitrary assumption of immediate clarity of the dream, is generally incomplete, if not astray, and often does not reveal the possible complexity of the feelings that contribute to the construction of the dream. The plausible association of distributed information with unconscious contents and of serial information with conscious contents, clearly expressed in the above cited review by Dehaene and Changeux (2011) is in agreement with the fact that the process of dream construction is essentially unconscious, while its output, the dream experience, is conscious, although in a way that is different from the consciousness of waking life. Of course, the unconscious character of the mechanism of dream construction from memory sources does not imply that these sources are unconscious as well: indeed, all of the present concerns and of the real-life events that were recognized in the above given examples were known by the dreamers. However, the phenomenon of the shift of the present concern shows that some contents, although being known by the dreamer, are not immediately recognized: this means that a significant form of involuntary reticence actually exists.

AUTHOR CONTRIBUTIONS

UB proposed the main idea of the paper after a discussion about the problem of seriality vs. parallelism in dreaming. All authors contributed to the above discussion. UB wrote the paper with many insights from PP and LS.

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ORIGINAL RESEARCH
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Reactions to Dream Content: Continuity and Non-continuity

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Although dream content may at times be quite outlandish or illogical, the dreamer's emotional reactions to these events are not outlandish or illogical. Our study shows that the dreamer's emotional reaction to people and events are similar to what they would have been in wake life. There is continuity between the emotional reactions of the dream and wake-self, even though situations may arise that are not likely or possible in wake life. For example, a dream may include people and places that span different times that are weaved together as if they were occurring at the moment. Further, the *behavior* of the dream-self is often different than that of the wake-self. When this happens, there is a non-continuity between the behavior of the dream and wake-self. Thus, there is both continuity and non-continuity between the dream and wake-self: Continuity in emotional reactions and non-continuity in the kinds of situations and behaviors that occur while dreaming. In the Kahn and Hobson, 2005a study, 58.7% of participants reported that their thinking *within* the context of the dream was similar to what it would have been had they been awake. About 55.1% of participants also reported that their thinking *about* the context of the dream was different than it would have been had they been awake. This difference affords the dream-self with novel experiences but that still elicit emotional reactions that are similar to how its wake-self would react. In essentially, every case when a comment was given to the question on thinking in the Kahn and Hobson, 2005a study, participants reported about how they emotionally reacted *within* the context of the dream and how they emotionally reacted *about* the content of the dream in comparison to how they would have reacted if awake.

Keywords: continuity, non-continuity, emotional reactions, dream-self, cognition

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INTRODUCTION: CONTINUITY AND NON-CONTINUITY

Cognition may be defined as the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses. The question addressed in this article is how cognition is the same and how it changes when we are dreaming and how this change may be helpful to the dreamer when awake.

When we dream, there is both continuity and non-continuity between the dream-self and the wake-self. There is continuity of the dream and wake-self's emotional reactions to events, people, and behavior. While implausible dream events often go unquestioned, the dreamer's emotional reaction to these events within the context of the dream is similar to wake-life reactions. This similarity suggests that the core person, asleep or awake, reacts similarly.

Non-continuity is in the occurrence of unlikely or impossible dream events and behaviors where people and places that span different times and different ages may be weaved together as if they were occurring in the moment.

Non-continuity provides the dream-self with new situations, such as when the dream-self interacts with her 5-year-old son, who in wake life is 15 years old, or when the dream-self interacts with a deceased parent. Continuity is because one's emotionaol reaction to the son or parent is similar to what they would have been in wake life even though the experience cannot occur when awake. Our wake and dream reactions remain tethered despite unlikely behaviors or logical inconsistencies in the dream.

The most common non-continuity between the dream and wake-self is in a character's behavior, Kahn and Hobson (2003). An example of non-continuity of behavior between the dream and wake-self might be if the dream-self is having sex with someone he or she would not in wake life. Does the dream-self feel guilty? How does the dream-self react? How to not get caught? Even if the behavior of the dream-self is unlikely to happen in wake-life, the emotional reactions of the wake-self would be the same as that of the dream-self, feeling guilty, how to not get caught, etc.

Having both, continuity and non-continuity between our dream and wake lives, helps explain both the cognitive connection and the disconnection between our dream and wake worlds.

Continuity between our dream and wake worlds may also be said to occur if dreams simulate and prepare us for social engagement when awake as in the theory of Revonsuo et al. (2016) and Tuominen et al. (2019). Continuity can also help with emotional well-being, Pesant and Zadra (2006), Cartwright (2010), Walker and van der Helm (2009), Walker (2017). Another example of continuity between the wake and dream worlds is the retaining of a theory of mind while dreaming, i.e., knowing what our dream characters are thinking, Kahn and Hobson (2005b).

Previous studies that have examined different kinds of non-continuity include those of Horton (2017) who has argued that non-continuity in dreaming has a functional role in the process of memory consolidation by separating memories from their original contextual role. They are taken out of their original context and are newly integrated with existing memories "rendering salient aspects of those memories to become available for retrieval in isolation from their contextual features."

Another benefit of non-continuity between the dream and wake-self is the making of unexpected associations and in the number and kind of associations that become linked during dreaming, e.g., see Horton and Malinowski (2015), Cai et al. (2009), Kahn and Gover (2010), Wagner et al. (2004), Stickgold et al. (1999). In the Stickgold et al. (1999) study, non-continuity between wake and dream sleep was explored through the use of a semantic priming task that measured the reaction time to find a word when it is preceded by a word that is associated with it. The study found that semantic priming was state dependent in that subjects awakened from REM sleep showed greater priming by weak primes than by strong ones during the REM carryover period. Subjects tested during normal wake hours showed greater priming by strong primes, as expected.

These unexpected and enhanced associations have been shown to enhance creativity in the wake state since creative problem solving improved if sleep contained REM, Cai et al. (2009). Subjects who had achieved REM sleep during a nap did better on a remote association task (RAT) than those who only had NREM or had no nap at all. These authors found that "REM enhances the integration of unassociated information for creative problem solving" (Cai et al., 2009).

Several other studies have demonstrated that after a night's sleep there is an enhanced ability to find a hidden rule or obtain an insight that helps solve a difficult problem. After waking from REM sleep subjects were often able to solve problems that were intractable during the day, Wagner et al. (2004), Walker and Stickgold (2004), Walker et al. (2002).

Previous studies that have examined different kinds of continuity between dream and wake experiences include those by Schredl and Hofmann (2003), Hobson and Schredl (2011), Schredl (2000, 2003, 2006), Horton (2017), Horton and Malinowski (2011), Malinowski et al. (2014), Malinowski and Horton (2011, 2015), Kahn and Hobson (2003, 2005a), Kahan and LaBerge (2011), Kahan et al. (1997), Domhoff (2011), Kozmová and Wolman (2006), Samson and De Koninck (1986), Sutton et al. (1994), Llewellyn (2011, 2013).

Dream Recall

Several of the above studies compared the ability to problem solve when awake with and without a previous nap or sleep containing REM. Several studies have also addressed the relevance of dream recall to enhanced problem solving after REM sleep, Blagrove (2007), Cartwright (2010), Schredl et al. (2003). Some of these have shown that dream recall, in fact, is relevant to problem solving. When we do recall dreams that have elements of a task previously learned, the dreams help improve performance on the previously learned task, Wamsley and Stickgold (2009, 2019). These authors showed that only when elements of the maze navigation task were incorporated in the dream did improvement occur after sleep.

Even if the dream is not recalled, the dream experience may still become a part of the general autobiographical and episodic memories that go into making up the core individual. The experience though not recalled into conscious awareness may become available on a non-conscious level as suggested in the study by Siclari et al. (2017). These authors found that high-frequency activity in prefrontal regions as occurs in dreaming "may mediate cognitive functions… such as encoding and storing long-term memories, … and planning and executing tasks." Further, according to Hobson (2009), whether dream recall happens or not, sleep and dreaming provide a protoconsciousness that is fundamental toward the eventual development of full consciousness.

METHODOLOGY

In this article, we have used the data from our original study on thinking (Kahn and Hobson, 2005a) to study the reactions of the dream-self to its own and to other dream characters' actions. In the original study, we did not rely on outside judges to determine what the dreamer was or was not thinking. We asked the dreamer to say whether thinking had occurred and if so what its characteristics were. The advantages and disadvantages of this protocol have been previously discussed (Kahn et al., 2002).

For this study, we reexamined the submitted dream reports in the original 2005a study for instances when not only thinking but also emotional reactions to dream events and people were reported in their comments on thinking. In the original study about thinking, emotional reactions to events and people were not explicitly excluded. In fact, comments of participants almost always mentioned their emotional reactions along with their thinking in their comments.

Sample Size

We first briefly review the sample and methodology of the original study. The sample consisted of 26 subjects, 24 young adults between the ages of 18 and 22 (15 women and 9 men attending a local college and not familiar with dream studies) and 2 older male adult subjects who are considered experts in dream studies.

The students submitted 151 dream reports over a 2-week period. The two older "dream expert" subjects submitted 27 dream reports over a 2-week period. The two population groups were combined since no substantial differences were found when the two population groups were considered individually.

The 26 participants submitted 178 dream reports in which there were 747 instances when thinking was reported to have occurred. Mean number of reports per subject was 6.8 (SD = 3.2). The mean number of words per report was 223 (SD = 112).

Upon awakening, participants in the study were asked to answer the question: would your thinking be the same as it was in the dream, if the event that occurred in the dream, occurred while awake? Please comment on how your thinking in the dream was the same or different than your thinking if awake.

Upon awakening, the participants were also asked to answer the question: "Would your thinking be the same regarding the occurrence of the event itself?"

RESULTS OF THE ORIGINAL AND CURRENT STUDY

The answers to these questions from the 26 subjects were analyzed with the aid of the statistical package "Statview 5.0." For each subject a mean value was calculated and from these an overall mean value. Most subjects replied that had their dream event occurred while awake, their thinking would have been the same as it was during the dream. The results are statistically significant. The majority of subjects also responded that their thinking *about* the occurrence of the event would not have been the same had they been awake. This difference was statistically significant to the $p = 0.02$ level. Thinking *within* the dream event was similar to waking but that thinking *about* the dream event was different. Subjects who said that their thinking *within* a dream event was the same as wake-state thinking, often went on to say that their thinking *about* the dream event was different than their wake state thinking. This combination was more than four times as common as its opposite; subjects rarely stated that their thinking within a dream event was different from their wake-state thinking and that their thinking about the dream event was the same as their wake-state thinking. All the above results were replicated when we calculated the two kinds of thinking on a per dream report basis as on the per dream event basis, reported above.

About 58.7% of the participants reported thinking *within* the context of the dream was the same, 32.9% reported thinking was different, and 6.4% could not decide. About 55.1% of the participants reported their thinking *about* dream context was different than it would have been had they been awake, 39.2% reported their thinking *about* dream context the same, and 3.5% could not decide.

The results from the original Kahn and Hobson, 2005a study are summarized below in **Figures 1** and **2**, further details may be found in the original.

Methodology in the Current Study

For the present study, we looked at the comments of the participants to these questions. It was discovered that almost all comments included participants' emotional reactions not just their thinking.

Below are examples of participants' answers to questions on thinking *within* and *about* a dream event when their emotional reactions were reported. These reactions both within and about a dream event are presented in tabular form (**Table 1**) below.

In essentially every case, when a comment was given, participants reported about how they reacted emotionally. They reported how they emotionally reacted *within* the context of the dream and how they emotionally reacted *about* the content of the dream in comparison to how they would have reacted

Descriptive Statistics

	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	# Missing
Y WITHIN EVENT/EVENT	.587	.183	.036	26	.250	.920	0
N WITHIN EVENT/EVENT	.329	.199	.039	26	.021	.750	0
? WITHIN EVENT/EVENT	.064	.108	.021	26	0.000	.468	0

FIGURE 1 | Thinking *within* a dream event. Descriptive statistics for the number of responses that thinking during a dream event would have been the same even if awake (Y within event/event), that thinking would have been different (N within event/event), and cannot decide if it would have been the same or not (? within event/event). The difference between subjects' responses is highly significant based on a paired *t* test for significance between subjects' responses from Kahn and Hobson (2005a).

Descriptive Statistics

	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	# Missing
Y ABOUT EVENT/EVENT	.392	.146	.029	26	.056	.750	0
N ABOUT EVENT/EVENT	.551	.196	.039	26	.182	.944	0
? ABOUT EVENT/EVENT	.035	.059	.012	26	0.000	.231	0

FIGURE 2 | Thinking *about* a dream event. Descriptive statistics for the number of responses that thinking *about* the dream event would have been the same even if awake (Y about event/event), that thinking would have been different (N about event/event), and cannot decide if it would have been the same or not (? about event/event). The difference between subjects' responses is significant based on a paired student *t* test for significance between subjects' responses from Kahn and Hobson (2005a).

TABLE 1 | Dream events, comments, and conclusions.

Participant	Dream event	Comment by participant	Conclusion
SF (m)	I was in my dorm room and I saw my roommate reclining on my bed. I saw this other guy, who started to molest him by running his fingers over his legs.	My roommate seemed to enjoy it, but I found it repulsive. "I was in a state of anger and that is how I would be in the same situation if I had been awake."	The dream and wake-self emotionally react the same.
SF (m)	I was annoyed at the woman taking too long to make up her mind to climb the ladder to open the hatch to get into the restaurant.	If awake, I would have been equally annoyed at the woman being so slow to make up her mind. But, if awake SF goes on to say he'd recognize the improbability of climbing a ladder to enter the restaurant through a hatch door.	If awake, SF's emotionl reaction would be the same as in the dream. Reaction *about* event is not the same.
JT (f)	We are on the way in and she is talking to me and says a swear word. I get really mad at her and call my dad to tell him what she just said, but he will not pick up his phone.	I would be mad at her if she swore when awake too. JT also said she would not call her dad if she did this.	Thus, JT's disapproval of swearing did not change, but her calling her dad not likely to happen.
LG (f)	I am in a race with a fat girl. I am happy because I know I can beat her. I look back and see that it is a guy chasing me and I panicked. I ran inside a house to throw the guy off. I knew he did not know where I was and I thought I might win the race, especially when I saw he stopped to make clay sculptures.	"If awake I would have thought that the guy was weird for abruptly stopping to do clay sculptures in the middle of our race. In the dream I just accepted it as an opportunity to win the race."	The dream self is happy to take advantage to win the race. Her desire to win is the same in waking and dreaming.
SF (m)	As I was retrieving the fallen paper towel, Dean R. was asking me about traveling and I replied by telling her about a trip I took to Washington DC	If, for whatever reason, Dean R. was talking to me, as awkward as I would feel, I would be as polite as I was in the dream.	Thus, the wake and dream-self emotionally act similarly. SF also said the event would be unlikely to happen.

if awake. This approach should be validated in a future study that *directly* asks participants about their emotional reactions to events and people in the dream.

DISCUSSION

The Kahn and Hobson (2005a) study found that thinking by the dream-self *within* the context of the dream was similar to that of the wake-self. Thinking by the dream-self *about* dream content was different than that of the wake-self in that the dream-self did not question dream content as its wake-self would.

The current study found that emotional reactions of the dream-self were similar to how its wake-self would react. If the dream-self became impatient, angry, or happy about its own or a dream character's behavior, its wake-self would have reacted the same. In general, participants reported that their emotional reactions *within* the context of the dream were similar to what its wake-self's would have been. The study also found that reactions between the dream and wake-self were different *about* implausible dream content. Implausible content would have been noticed by its wake-self.

Thus, there is both continuity and non-continuity while dreaming. While the wake-self would not (or could not) engage in some of the behaviors of the dream-self, the result that emotional reactions of the dream-self and wake-self are similar shows that a continuity exists between the dream-self and the wake-self.

The non-continuity part is that the dream and wake-self's reactions to unlikely and improbable events are different. However, bizarre upon awakening, *within* the dream, events go unquestioned and are accepted as occurring in the here and now. This acceptance is one reason that our emotional reaction to events and people within the dream are not different than when awake. The result that there is continuity between the dream-self and wake-self in their emotional reactions to events suggests that emotional reactions are state-independent, occurring in both the dream and wake states.

Continuity, Non-continuity, Brain Changes, and Emergence

It is, in fact, remarkable that there is continuity between the dream and wake-self given how the brain's chemistry and neural activity have changed from waking to dreaming and the fact that the emergent dream is different than its individual source elements, Kahn (2013, 2016). Serotonin and norepinephrine are absent in rapid eye movement (REM) dreaming, and reduced in NREM dreaming. No longer is the brain presented with a balanced concentration of cholinergic and aminergic chemistry, and no longer is the neural activity of the executive portions of the prefrontal areas as active as in the wake state, Braun et al. (1997), Maquet (2000), Cicogna and Bosinelli (2001), Hobson et al. (2000), Nir and Tononi (2010), Siclari et al. (2017). This study suggests that despite the brain changes that give rise to non-continuity between dream and wake content, continuity between the dream and wake-self's emotional reactions *within* the context of the dream persists. This, in turn, suggests that core personality traits are state-independent.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Different Patterns of Sleep-Dependent Procedural Memory Consolidation in Vipassana Meditation Practitioners and Non-meditating Controls

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Aim: Rapid eye movement (REM) sleep, non-rapid eye movement (NREM) sleep, and sleep spindles are all implicated in the consolidation of procedural memories. Relative contributions of sleep stages and sleep spindles were previously shown to depend on individual differences in task processing. However, no studies to our knowledge have focused on individual differences in experience with Vipassana meditation as related to sleep. Vipassana meditation is a form of mental training that enhances proprioceptive and somatic awareness and alters attentional style. The goal of this study was to examine a potential role for Vipassana meditation experience in sleep-dependent procedural memory consolidation.

Methods: Groups of Vipassana meditation practitioners (N = 22) and matched meditation-naïve controls (N = 20) slept for a daytime nap in the laboratory. Before and after the nap they completed a procedural task on the Wii Fit balance platform.

Results: Meditators performed slightly better on the task before the nap, but the two groups improved similarly after sleep. The groups showed different patterns of sleep-dependent procedural memory consolidation: in meditators, task learning was positively correlated with density of slow occipital spindles, while in controls task improvement was positively associated with time in REM sleep. Sleep efficiency and sleep architecture did not differ between groups. Meditation practitioners, however, had a lower density of occipital slow sleep spindles than controls.

Conclusion: Results suggest that neuroplastic changes associated with meditation practice may alter overall sleep microarchitecture and reorganize sleep-dependent patterns of memory consolidation. The lower density of occipital spindles in meditators may mean that meditation practice compensates for some of the memory functions of sleep.

Keywords: procedural memory, memory consolidation, vipassana meditation, REM sleep, NREM sleep, sleep spindles, body awareness

INTRODUCTION

A wealth of research supports a role for sleep in explicit and implicit memory consolidation (for reviews see Diekelmann and Born, 2010; Stickgold, 2013; Shönauer and Gais, 2017). Sleep is thought to strengthen information learned during the day, to select which experiences are best remembered and which are best forgotten, and to assimilate new knowledge into existing autobiographical networks (Walker and Stickgold, 2010; Rolls et al., 2013; Stickgold and Walker, 2013; Deliens and Peigneux, 2014). While most research to date has focused on the effects of a full night of sleep, an increasing number of studies report that daytime naps have effects that are similar to those of nighttime sleep on memory processes (Mednick et al., 2003; Backhaus and Junghanns, 2006; Nishida and Walker, 2007; Lahl et al., 2008; Seeck-Hirschner et al., 2010; Fogel et al., 2014; Lo et al., 2014; Korman et al., 2015).

Current research in cognitive science focuses strongly on contemplative practices and their effects on physical and mental health. Such practices include an element of cultivating access to and awareness of increasingly subtle bodily sensations (Kerr et al., 2013; Zeng et al., 2014). Meditation practitioners can be considered an “expert” group of healthy individuals who intentionally cultivate attention to bodily states and are better able to access and employ them (Fox et al., 2012), thus potentially embodying some cognitive processes differently. However, it is still unknown whether meditators may rely more upon awareness of somatosensory and other types of endogenous information to encode memories for skill learning.

In this study, we investigate whether Vipassana, a specific meditation practice focusing on body awareness, changes the neurobiological qualities of sleep-dependent memory consolidation. Specifically, we chose a full body procedural memory task and a daytime nap protocol to test whether: (1) meditation practitioners and meditation-naïve controls differ in performance and improvement on a procedural balance task; (2) the two groups differ in their patterns of sleep stage and sleep microarchitecture in reaction to the task; and (3) daytime nap sleep characteristics (sleep stages and sleep spindles) in meditation practitioners are similar in quality to nighttime sleep.

Consolidation of procedural memory – skill learning – during sleep has been studied using a number of tasks, including sequential finger tapping (Benedict et al., 2009; Doyon et al., 2009; Van Der Werf et al., 2009; Dresler et al., 2010; Genzel et al., 2011; Holz et al., 2012b; Wamsley et al., 2012; Antonenko et al., 2013), serial-reaction time task (Galea et al., 2010; Prehn-Kristensen et al., 2011; Ertelt et al., 2012), motor sequence task (Tucker and Fishbein, 2009; Manoach et al., 2010), mirror-tracing task (Smith et al., 2004b; Javadi et al., 2011; Puetz et al., 2011; Holz et al., 2012a), button-box sequence (Wilhelm et al., 2012), visuomotor adaptation task (Doyon et al., 2009); texture discrimination task (Gais et al., 2008; Cipolli et al., 2009), visual discrimination task (Suzuki et al., 2012), and others. These tasks usually involve fine motor skills using the fingers or hand-eye coordination, but do not typically involve balance or bodily displacements. Tasks involving balance skills or full-body learning have only rarely been used in memory consolidation research (Buchegger and Meier-Koll, 1988; Buchegger et al., 1991; Tjernstrom et al., 2005). While hand-eye coordination tasks are well-validated and are easy to implement, full-body tasks may be more representative and ecologically valid with relation to global procedural memory skills. Many daily behaviors considered as procedural skills rely on greater involvement of vestibular and kinesthetic systems (e.g., navigating different spaces, sports, bicycling, cooking, tool use, etc.), and some involve fine motor skills (e.g., typing, using smartphones, specialized tool use). Thus, full-body procedural learning may provide additional insights into global processes underlying sleep-dependent memory consolidation.

Some studies suggest particular sleep macro (sleep stages) and micro architecture aspects to be important for procedural memory consolidation. For example, NREM sleep duration (Walker et al., 2002) as well as NREM electrophysiological events, such as sleep spindles (Barakat et al., 2011; Fogel et al., 2017), have been associated with post-sleep task improvement. The sleep spindles, phasic events (0.5- to 3.0-s duration) characterized by bursts of 11–16 Hz EEG activity occurring predominantly during stage 2 NREM (N2) sleep, are of particular interest. Converging evidence points to possible different neural mechanisms implicated in fast and slow sleep spindles (Molle et al., 2011), but few studies to date have examined the combined contribution of slow and fast sleep spindles to memory consolidation. In one recent study, fast (but not slow) sleep spindles were involved in transfer or implicit knowledge to more explicit awareness (Yordanova et al., 2017). In another study, consolidation of face memory, which can be considered as having both explicit and implicit components, was associated with both fast and slow sleep spindles (Solomonova et al., 2017).

Sleep’s role in memory consolidation is not only influenced by task type and sleep stage/sleep microarchitecture, but also by individual differences in learning abilities and cognitive styles. In one study, for example the ability to bring a motor task into explicit awareness improved post-sleep performance on the task (Robertson et al., 2004). This suggests that training in a particular kind of attentional engagement with the learning task may change the neurocognitive style of offline memory processing and affect performance. Contemplative practices (e.g., meditation and mindfulness) can be considered as one particular way of attentional engagement. Vipassana meditation is one such practice. It is characterized by developing sustained and systematic practice of being aware of one’s bodily sensations, with an aspiration to ultimately gain insight into the nature of the mind (Hart, 1987; Goenka, 1997; Chavan, 2008). Practitioners typically start with a focused attention practice – mindfulness of breathing – and continue with the practice of the body scanning technique, which is the main particularity of Vipassana. During the second part of the practice, meditators are instructed to mentally examine their bodily states to become aware of subtle sensations and, ultimately, to approach them with equanimity. This contemplative tradition may change practitioners' cognitive style in a global way, including changing processes of attention, memory encoding, consolidation and retrieval.

Studies show that Vipassana meditation yields beneficial effects of decreasing stress and improving well-being (Szekeres and Wertheim, 2015), helping generate greater perceptual clarity and decrease automated reactivity to stimuli (Cahn and Polich, 2009; Cahn et al., 2013; Delgado-Pastor et al., 2013), and decreasing anger, hostility and depressive symptoms (Kasai et al., 2015). Other studies report improved psychological well-being (Montero-Marin et al., 2016) and cognitive flexibility (Kasai et al., 2015). Other effects of Vipassana training include increased somatosensory awareness, e.g., increased awareness of pain, more spontaneous body movements, increased mindfulness, and development of equanimity, or the ability to adapt to extreme changes in lived experience (Kornfield, 1979). Sleep architecture changes of Vipassana practitioners are few, but include longer REM sleep periods when compared to controls and yoga practitioners (Sulekha et al., 2006). Longer-term practitioners (over 7 years of daily practice) have more N3 sleep, less N2 sleep, fewer awakenings from sleep and an altered pattern of REM sleep microarchitecture (Maruthai et al., 2016).

Although it may seem intuitive to consider that meditation practice affects learning and memory by enhancing specific cognitive and attentional skills (Valentine and Sweet, 1999; Jha et al., 2007; Zeidan et al., 2010), few studies to date have directly addressed the effect of meditation on memory consolidation, with mixed results. One study reports very few differences between long-term meditation practitioners (including Vipassana meditators) and non-meditating controls: meditators showed better performance on short-term and free recall long-term memory (Lykins et al., 2012). Other studies report improvements in working memory in meditation practitioners (Mrazek et al., 2013; Basso et al., 2019), specifically, in a military cohort (Jha et al., 2010), and in a group of adolescents (Quach et al., 2016). With respect to procedural motor memory, only one other study to our knowledge assessed contribution of post-training meditation practice to memory consolidation (Immink, 2016): experienced yoga *nidra* meditation practitioners showed post-training memory benefits on a sequence tapping task.

In sum, both sleep stages and sleep microarchitecture have been associated with procedural learning. The patterns of sleep-dependent learning may reflect individual learning styles and thus may be different in meditation practitioners. Vipassana meditation may produce changes in body awareness, which in turn may influence not only individual health and cognitive patterns, but also the style of encoding of procedural memory. In the current study, we hypothesize that: (1) following a daytime nap, Vipassana meditators (MED group) will show more improvement on a procedural task than will meditation-naïve controls (CTL group). We also hypothesize (2) that the MED and CTL groups will express two distinct neurobiological learning patterns: the MED group will show a NREM-dependent pattern, reflecting a more explicit learning process; more specifically, fast sleep spindles will correlate with task improvement. In contrast, the CTL group will show a REM-dependent pattern, consistent with previous research on non-declarative learning.

MATERIALS AND METHODS

Participants

Forty-two male (n = 21) and female (n = 21) participants between the ages of 18 and 35 years (M = 25.4 ± 4.4) were recruited for a daytime nap study via online advertisements, and subsequently screened via phone or online questionnaire. In the MED group there were 22 participants (*M*age = 25.8 ± 4.1, 11 men, 11 women) and in the CTL there were 20 participants (*M*age = 25.0 ± 4.8, 10 men, 10 women). Inclusion criteria for both groups were: 18–35 years of age, high dream recall (3+ per week), good self-reported physical/mental health, no sleep disturbances (e.g., shift work or jet lag). To be included in the MED group, Vipassana practitioners had to have taken part in at least one 10-day retreat, which consists of approximately 100 h of practice, and to be currently practicing Vipassana meditation on at least a weekly basis. Participants completed an informed consent form approved by the Hôpital du Sacré-Coeur de Montréal ethics board. They were financially compensated for the time spent in the laboratory, parking or public transit, and lunch expenses.

Body Awareness

Body awareness was measured using the Scale of Body Connection (SBC) questionnaire (Price and Thompson, 2007) This scale consists of 20 items each scored on 0–4 scales and which produces two independent subscales: body awareness (12 items) with items that assess awareness of, e.g., tension, bodily stress, breath, and emotional state, and bodily dissociation (eight items) with items that assess, e.g., feeling frozen/numb, separated from the body, and difficulty in expressing emotions. Subscale scores consist of the average ratings of constituent items (0–4). The questionnaire has been validated on studies of bodily awareness in women with substance abuse disorder (Price et al., 2012), of exercise and body awareness therapy in major depression (Danielsson et al., 2014), of body therapy for survivors of childhood sexual abuse (Price, 2007), and of interoceptive awareness of breathing in experienced meditation practitioners (Daubenmier et al., 2013).

Procedure

Participants arrived in the laboratory at 9:00 am and completed a consent form and a battery of questionnaires, which included the SBC. They then completed the procedural task and had the PSG setup installed. Immediately before lights-out, the MED group meditated in bed for 10 min and the CTL group simply relaxed for the same amount of time. All participants were then given a window of opportunity to sleep of approximately 90 min. They were awakened twice with a non-stressful, 80 dB, 500 Hz, once at sleep onset and once at the end of the nap. At these times, spontaneous dream reports and dream questionnaires were completed. Following the second awakening, electrodes were removed and participants repeated the procedural task.

Procedural Memory (Balance) Task

Participants performed a procedural memory task requiring whole body balance, i.e., a video game entitled "Balance bubble" for the Nintendo Wii Fit Balance Board. In this task, participants control a virtual character that moves along a river in a bubble by shifting their weight on the Balance Board. The objective is to complete the river path as quickly as possible without touching the river's edges and thus bursting the bubble. Bursting the bubble required the participant to start again from the beginning of the path. The task was performed on a 42-in. television screen. All participants were assessed for any vision correction and instructed to wear their glasses or contact lenses if needed. Participants had a 2-min period to acquaint themselves with the task, and to ask questions of the experimenter, who ensured that participants clearly understood the requirements of the game. The total maximum game time was 90 s, and participants were allowed to repeat the task until a total of 5 min of gameplay had elapsed. Participants were instructed to attempt to complete the task as many times as possible during the 5-min period. The task was performed once before lights-out (T1) and once after awakening (T2).

The following variables were calculated to assess performance on the task: highest score on all attempts averaged; the number of times participants completed the task by arriving at the end of the "river"; average score in game "meters" over all attempts at the game, and average time spent correctly balanced in the bubble over all attempts. Two measures of improvement on the task were used: T2–T1GameScore (average score after nap minus average score before nap), and T2–T1Time (average time after nap minus average time before nap).

Polysomnography

Participants slept in a quiet bedroom under continuous audio-visual monitoring with a two-way intercom. A standard polysomnographic montage was used: six EEG channels (F3, F4, C3, C4, O1, O2) referenced to A1 and re-referenced to A1 + A2 offline; four electrooculography (EOG) channels (horizontal and vertical), and three electromyography (EMG) channels (chin, wrist, leg). Acquisition of EEG signals was done using an M15 Grass Acquisition System (−6 dB filters with cut-offs at 0.30 and 100 Hz) and Harmonie v6.2b software (Natus Medical Incorporated, Pleasanton, CA, United States). Sleep stages were scored according to standard criteria (Iber, 2007) by an experienced technician and standard sleep variables were calculated using in-house software.

Sleep spindles were detected on artifact-free sleep epochs recorded from F3, F4, C3, C4, O1, and O2 derivations by an in-house detector. The full detection algorithm is described by Nielsen et al. (2016) and by O'Reilly and Nielsen (2014). Spindles were separated into slow (10.00–12.99 Hz) and fast (13.00–16.00 Hz) types and densities calculated as the number of spindles of each type divided by time elapsed in N2 sleep.

RESULTS

Body Awareness

A total of 32 participants (15 MED and 17 CTL; 80%) returned questionnaires by mail. Independent samples t-tests on the SBC score and Body Awareness and Bodily Dissociation subscales revealed, as predicted, that the MED group scored significantly higher on Body Awareness than did the CTL group (M(MED) = 0.243 ± 0.060; M(CTL) = 0.194 ± 0.061; $t(30) = -2.289$; $p = 0.029$; Cohen's $d = -0.81$; 95% CIs [−1.529, −0.081]) but did not differ on Bodily Dissociation. Body Awareness was not correlated with years of meditation experience in the MED group ($r = -0.471$, $p = 0.077$).

The MED group showed positive correlations between Body Awareness and average time ($r = 0.580$; $p < 0.05$) and score ($r = 0.518$; $p < 0.05$). In contrast, CTL participants showed no significant correlations were observed between Body Awareness scores and task performance measures.

Task Performance

Separate repeated-measures ANOVAs with average time spent balanced, average score, and highest score obtained as within subjects factors and with condition (MED or CTL) as between subject factors revealed that both groups improved on average time ($F(1) = 20.172$, $p < 0.001$), score ($F(1) = 60.564$, $p < 0.001$), and highest score obtained ($F(1) = 29.546$, $p < 0.001$). No group effect was observed for either time ($F(1) = 0.209$, $p = 0.650$) or score ($F(1) = 0.477$, $p = 0.494$). A significant group effect, however, was observed for highest score obtained ($F(1) = 4.474$, $p = 0.041$). The follow-up independent samples t-test showed that the highest score obtained at T1 was significantly higher in MED than in CTL (M(MED) = 1028.4 ± 142.21; M(CTL) = 913.3 ± 187.54; $t(38) = 2.188$; $p = 0.035$).

In addition, meditators finished the game more often, especially after the nap: 2 (10%) of CTL participants finished the task at least once before the nap (T1), compared with 5 (25%) of MED participants ($\chi 2 = 0.693$, $p = 0.405$, 2-tailed, Yates corrected) whereas 6 (30%) of CTL participants finished the task after the nap (T2) compared with 12 (60%) of MED participants ($\chi 2 = 3.636$, $p = 0.057$). No other differences in task scores were observed between the groups.

Sleep Structure

Two MED participants was dropped from spindle analyses due to insufficient sleep duration. No statistically significant differences between MED and CTL groups were observed for any sleep characteristic, except for a trend ($p = 0.09$) for CTL participants toward overall longer sleep duration (see **Table 1** for complete results).

Relationship Between Sleep and Meditation Experience

To test the relationship between cumulative lifetime meditation experience and sleep architecture, Spearman correlations analyses were performed for self-reported meditation experience in the MED group (in hours), and duration of individuals sleep

TABLE 1 | Sleep measures for Vipassana meditators (MED: $N = 20$) and non-meditating controls (CTL: $N = 20$).

Sleep characteristic	Mean MED ± SD	Mean CTL ± SD	*t*	df	*p*	Cohen's *d*
Total sleep duration (min)	65.98 ± 25.27	78.30 ± 19.32	−1.73	38.00	0.09†	0.55
Sleep latency (min)	8.78 ± 6.75	14.35 ± 20.08	0.20	38.00	0.84	−0.06
REM latency (min)	16.35 ± 22.35	20.74 ± 31.23	−0.47	32.00	0.64	0.16
Sleep efficiency	73.66 ± 23.10	81.70 ± 13.31	−1.31	29.68	0.20	0.42
N1 duration (min)	7.13 ± 7.67	7.03 ± 3.81	0.05	38.00	0.96	−0.02
N2 duration (min)	32.83 ± 16.47	36.05 ± 15.05	−0.65	38.00	0.52	0.20
N3 duration (min)	15.05 ± 13.38	22.53 ± 18.99	−1.44	38.00	0.16	0.46
Total NREM duration (min)	55.00 ± 23.28	65.60 ± 22.37	−1.47	38.00	0.15	0.46
REM duration (min)	10.98 ± 6.12	12.70 ± 9.99	−0.66	38.00	0.51	0.21
Wake duration (min)	24.75 ± 24.71	17.45 ± 12.33	1.18	27.91	0.24	−0.37
N1%	13.31 ± 16.30	10.45 ± 8.94	0.69	38.00	0.50	−0.22
N2%	50.55 ± 17.18	45.10 ± 15.68	−0.90	38.00	0.50	−0.29
N3%	19.46 ± 15.95	26.45 ± 20.43	−1.21	38.00	0.24	0.38
NREM%	83.32 ± 10.68	82.90 ± 15.17	0.10	38.00	0.92	−0.03
REM%	16.69 ± 10.68	17.11 ± 15.17	−0.10	38.00	0.92	0.03
Wake%	26.29 ± 24.02	18.30 ± 13.31	1.30	29.66	0.20	−0.41
N awakenings	5.65 ± 3.84	6.70 ± 4.18	−0.83	38.00	0.41	0.26

$^{\dagger}p < 0.10$.

stages (N1, N2, N3, REM, in minutes). We observed a strong negative correlation between cumulative lifetime meditation experience and time in N2 sleep ($r_s = -0.546$, $p = 0.015$) but no correlations with other sleep stages.

Sleep Spindles

A total of 20 CTL and 19 MED subjects were compared (**Figure 1** for group comparisons of spindle density). Distribution of spindle density was moderately to highly skewed for most spindle measures, thus non-parametric Mann–Whitney independent samples U-tests were used for analyses involving spindle measures. There were no significant group differences in total spindle density or fast spindle density. However, the MED group showed lower slow spindle densities in occipital derivations, specifically: a lower spindle density in O1 (M(MED) = 1.077 ± 0.819; M(CTL) = 1.754 ± 0.995; $U = 277$; $p = 0.015$; $r = 0.461$; 95%CIs [0.130, 0.699]) and a lower slow spindle density in O2 (M(MED) = 1.225 ± 0.842; M(CTL) = 1.848 ± 1.035; $U = 264$; $p = 0.039$; $r = 0.389$; 95%CIs [0.044, 0.652]). See **Figure 1** for complete spindle comparison between groups.

Sleep and Procedural Memory Consolidation

To assess the relationships between sleep and improvement on the balance task, the two most sensitive task measures were used: change in average *time* spent in balance (T2–T1) and change in average *score* (T2–T1). The decision to use these scores was based on the fact that *time* and *score* represented two main facets of successful performance on the task. Time spent in balance (even when score was low) showed how stable participants were on the platform, and score one the task (independent of how fast the task was completed) showed how far they got in the game. Spearman correlations were calculated to evaluate dose-response relationships between change in sleep stages, task performance, and slow and fast spindle density.

Sleep Stages

For the MED group, there were no statistically significant relationships between task improvement scores (average time and average score) and sleep stages (NREM: N1, N2, N3, and REM). For CTL group, improvement on average time spent balanced correlated negatively with N1 duration ($r = -0.465$, $p = 0.007$) and positively with REM sleep duration ($r = 0.592$, $p = 0.006$). Further, improvement on average score correlated negatively with N1 duration ($r = -0.470$, $p = 0.037$); and positively with REM sleep duration ($r = 0.536$, $p = 0.015$). Improvement on average score also correlated with several other sleep measures which were not predicted, i.e., negatively with sleep latency ($r = -0.475$, $p = 0.034$); positively with sleep efficacy ($r = 0.451$, $p = 0.046$); and negatively with wake duration ($r = -0.498$, $p = 0.025$). See **Table 2** for complete results.

Sleep Spindles

Spearman correlations between measures of task improvement (T2–T1Time and T2–T1GameScore) and sleep spindle densities revealed significant relationships for the MED group, but not the CTL group. T2–T1Time correlated positively with density of slow sleep spindles in O1 ($r_s = 0.463$, $p = 0.047$). T2–T1GameScore correlated positively with density of slow sleep spindles in O1 ($r_s = 0.489$, $p = 0.035$); and showed negative trend correlations with density of fast sleep spindles in O1 ($r_s = -0.400$, $p = 0.091$); and negatively with density of fast sleep spindles in O2 ($r_s = -0.391$, $p = 0.099$).

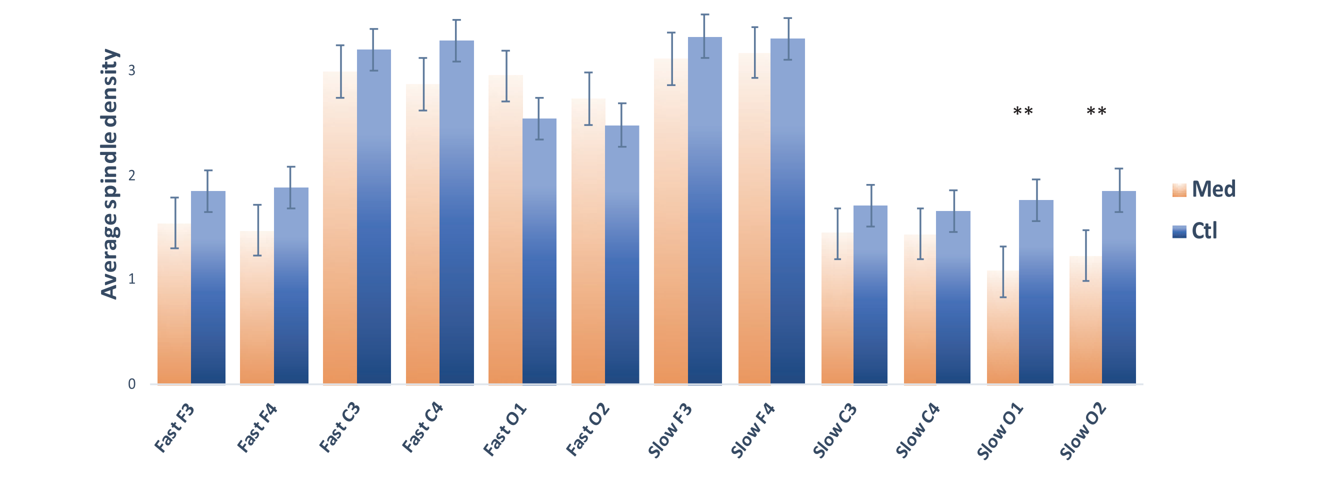

FIGURE 1 | Sleep spindle densities (M ± SEM) for Vipassana meditators (MED; $N = 20$) and non-meditating controls (CTL; $N = 20$). Spindle density calculated as the number of sleep spindles/time in NREM2 sleep. $^{**}p < 0.05$.

DISCUSSION

This study is the first to examine sleep-dependent memory consolidation in meditation practitioners. Although meditators were found to perform slightly better on the balance task at first testing than controls (meditators were able to complete the task more often), both groups improved to a similar extent after a morning nap. However, distinct patterns of relationships between task improvement and sleep structure were observed for the two groups: meditators showed a relationship between task improvement and occipital NREM sleep spindles while controls showed a relationship between task improvement and REM sleep time. In addition, we found differences in spindle density between meditators and controls, with meditators having significantly lower spindle density in occipital regions. These results together suggest that meditation experience may contribute to large-scale changes in the electrophysiological indicators of neuroplasticity during sleep.

TABLE 2 | Pearson correlation coefficients between sleep characteristics and post-nap improvement in performance on a procedural task in meditators (MED) and controls (CTL).

	MED		CTL	
Sleep variable	**Time**	**Score**	**Time**	**Score**
Total sleep duration	0.31	0.06	−0.10	0.01
Sleep latency	0.16	0.20	−0.20	−0.48**
REM latency	−0.02	0.18	0.28	0.26
Sleep efficiency	0.20	0.04	0.29	0.45**
N1 duration	0.01	−0.09	−0.47**	−0.47**
N2 duration	0.22	0.14	−0.39*	−0.23
N3 duration*	0.20	−0.01	−0.01	0.01
Total NREM duration*	0.30	0.06	−0.35	−0.23
REM duration	0.11	0.00	0.59***	0.54**
Wake duration	−0.15	−0.02	−0.32	−0.50**
N1%	−0.11	−0.14	−0.41*	−0.42*
N2%	0.02	0.20	−0.42*	−0.33
N3%	0.12	−0.07	−0.01	0.00
NREM%	0.05	−0.01	−0.66***	−0.57***
REM%	−0.05	0.01	0.66***	0.57***
Wake%	−0.20	−0.04	−0.29	−0.45**

Average improvement in time and in score is reported. $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$ *(Conservative error rate adjustment for 32 correlations per group = 32/0.05 = 0.002).*

Different Sleep-Dependent Memory Consolidation Styles in Meditators and Controls

Results support the study's main hypothesis that Vipassana meditation practitioners, potentially by virtue of training in attending to bodily states and stimuli, may rely upon a different neurobiological learning style, one that manifests in distinct changes in sleep microarchitecture. Specifically, meditation practitioners showed relationships between the density of slow and fast occipital spindles in N2 sleep and task improvement. While slow occipital spindle density correlated positively with task improvement, fast occipital spindle density showed a trend toward the opposite. Meditators did not, however, show any links between duration of REM or NREM sleep stages and task improvement. On the other hand, non-meditating controls did show a strong positive correlation between time in REM sleep and task improvement. This is consistent with previous research where, in a series of studies, a novel motor skill, in this case jumping on a trampoline, was associated with increased REM sleep (Buchegger and Meier-Koll, 1988; Buchegger et al., 1991). Our results partially replicate these findings to the extent that improvement on our procedural balance task was associated with length of REM sleep during the daytime nap for control participants only. They did not, however, show any links between sleep spindles, especially fast sleep spindles, and task improvement. Both of these findings have been reported in previous studies. To illustrate, for the N2 spindle finding among meditators, we previously reported similarly perpendicular relationships between fast and slow spindles in relation to learning: fast N2 spindles correlated positively and slow spindles correlated negatively with face recognition (Solomonova et al., 2017). For the REM sleep finding in controls, earlier research similarly linked duration of REM sleep with implicit memory consolidation (Karni et al., 1994). We also report a relationship between performance on the balance task and other sleep variables for the non-meditating control group. For instance, moderate correlations were found between overall sleep quality and improvement on task (positive correlation with sleep efficacy and negative correlations with wake duration and with N1 duration). This potentially reflects the overall beneficial role for sleep quality (higher efficiency, less fragmentation) in memory consolidation. In addition, higher sleep efficacy, lower N1 sleep time and lower wake time are all related to higher chances of reaching REM sleep during the nap, and thus are likely related to our REM sleep finding.

Different Styles of Post-Task Sleep-Dependent Processing?

One interpretation of these findings is that meditation practitioners approach a procedural full-body balance task in a more "explicit" manner, in the sense that they are able to bring to awareness elements of their somatic and bodily experience that usually remain unconscious among untrained individuals. Their greater familiarity with bodily sensations may thus have allowed them to perform somewhat better on some, but not all, aspects of the task. They performed slightly better than the control group on the task overall, achieving higher maximum scores both before and after the nap. This advantage may reflect a shift in the neuroplasticity mechanisms that were brought to bear on the task during sleep. This idea is consistent with the suggestion (Smith et al., 2004a) that REM sleep is associated with processing of complex tasks while Stage 2 sleep benefits the consolidation of simpler tasks. Smith et al. (2004a) propose that the involvement of REM or Stage 2 sleep in consolidation of a motor task depends on perceived complexity of the task; participants who are less skillful at the outset will show a dependence on REM sleep and those who find the task easier will show a N2 dependence. Because our meditators scored higher in body awareness and possibly found the task slightly easier, they may have needed only N2 spindle mechanisms to refine their learning. In contrast, if control participants found the task more complex or novel, they may have had a greater need for REM sleep control mechanisms.

Despite the feasibility of this explanation, the significance of several additional findings from the current study remain unclear. One is the question of why meditators had a lower rate of occipital spindles when sleep spindle density was associated with task improvement. A second outstanding question is why slow rather than fast sleep spindle densities were associated with task improvement. Many previous studies (Tamaki et al., 2009; Barakat et al., 2011; Lustenberger et al., 2016) report that fast spindle density is preferentially correlated with improvement on procedural tasks. However, a growing body of evidence supports the notion that slow spindles are also a reliable correlate of procedural learning in some contexts. Nishida et al. (2016) showed a negative association between slow spindle power and a finger-tapping motor tracing task in depressed but not in healthy participants. A second group (Holz et al., 2012a) showed a positive correlation between slow spindle activity (sigma: 12–14 Hz) in NREM sleep and improvement on a mirror tracing task. Third, studies have shown that slow spindles are associated with explicit memory consolidation on tasks such as word-lists (Holz et al., 2012a) and auditory verbal learning and declarative learning in epileptic patients (Del Felice et al., 2015). Fourth, in children, slow sleep spindle activity was found to be associated with declarative learning efficiency (Hoedlmoser et al., 2014). Finally, in a study using daytime naps (Schmidt et al., 2006), participants learning difficult and easy word-pairs showed evidence of slow spindle associations with improvement only on the difficult pairs. Such converging evidence links slow spindles to procedural learning and is consistent with our finding that meditators reacted to the balance task as a procedural task requiring N2 sleep mediation.

Possible Napping Profile

A second possible explanation of our group differences in sleep-dependent effects is that meditators are conforming to a profile known to characterize habitual nappers, either because they are used to taking frequent naps or because periods of daytime meditation may confer advantages similar to those provided by sleep, especially theta-rich Stage 1 NREM sleep (Aftanas and Golosheykin, 2005). Unfortunately, our findings do not further clarify the first point because we did not collect information about habitual napping practices. Yet, there is evidence (Milner et al., 2006) that individuals habitually taking daytime naps show a relationship between motor task improvement and sleep spindles whereas non-habitual nappers do not. Such findings, together with evidence that meditation practitioners commonly fall asleep during meditation sessions (Pagano et al., 1976), provides some support for the notion that meditation confers either sleep-dependent or sleep-like advantages in memory consolidation. However, more research taking into account the habitual napping practices of participants is clearly needed for this explanation to be considered probable.

The notion that meditation practice leads to a different style of learning is consistent with both the philosophy of meditation approaches and a growing body of research. Indeed, the underlying goal of most traditional meditation practices, including Vipassana meditation, is not simple training of attentional acuity, but rather development of insight into one's own patterns of reactivity in order to decrease unwholesome traits and increase wholesome traits and behaviors (Hart, 1987; Goenka, 1997). Ultimately, the goal is not to improve at meditation, but to improve at life skills more generally. Thus, neuroplastic changes and acquired mental skills associated with meditation practices may have an important effect on changing one's cognitive, emotional and memory patterns more broadly (Hasenkamp and Barsalou, 2012). This idea is consistent with previous findings, including those from a study wherein mindfulness training led to increased somatosensory awareness of the experience of sadness, which in turn was related to decreased depression (Farb et al., 2010). Neurophysiologically, meditation training may change the functional connectivity associated with bodily representation and thereby recruit the interoceptive skills that underlie several perceptual and cognitive tasks (Farb et al., 2013). Our findings are thus consistent with the notion that Vipassana practice, through increased interoception and body awareness, facilitates the development of cognitive skills and thereby differentially influences sleep's reactions to new procedural learning tasks.

Task Performance, Body Awareness, and Bodily Dissociation

We previously reported (Solomonova, 2018), that meditation practitioners did not differ from non-meditating controls on most aspects of task performance. As predicted, however, meditators scored higher than controls on the Body Awareness subscale of the Scale of Body Connection and these scores were related to task performance (time and score) before the nap. These finding are consistent with studies suggesting that sustained meditation practice contributes to higher levels of somatic awareness (Fox et al., 2012) and confirms our rationale for choosing a full-body balance task to examine patterns of sleep-dependent memory consolidation. In this case, one required skill for learning the task quickly is a heightened level of attunement to one's own bodily/somatic states.

Sleep and Spindle Differences Between Meditators and Controls

Sleep Architecture

In contrast to existing literature on sleep in Vipassana practitioners, we did not find longer REM sleep or SWS periods in meditation practitioners or differences in sleep efficiency or #awakenings, but meditators did show a tendency for a lower overall sleep time. This is consistent with the results of a study on Mindfulness-Based Cognitive Therapy, whereas meditation practitioners showed more cortical arousal and more awakenings during nighttime sleep than did controls (Britton et al., 2010). On the other hand, in another study, experienced long-term Buddhist practitioners (Ferrarelli et al., 2013) had a lower total sleep time, like the trend in our study, but also more awakenings.

The fact that we found no associations between meditation experience and sleep latencies, sleep efficiency or duration/proportion of individual sleep stages may be due to the fact that our sample contained no expert meditation practitioners, typically quantified as having more than 10 000 h of meditation practice (Brefczynski-Lewis et al., 2007). Because all our participants are considered meditation novices or at best intermediate practitioners, it is possible that the short daytime naps taken were insufficiently sensitive to reveal subtle group differences. Future studies might require all-night recordings or protocols that unmask subtle group differences by augmenting homeostatic pressure or REM sleep propensity.

Sleep Spindles

We found sleep spindle density differences between meditators and controls, with meditators unexpectedly showing reduced sleep spindle density in occipital derivations. Reduced spindle density has been suggested as a marker of neurodegeneration (Ktonas et al., 2007; Latreille et al., 2015) and psychopathological conditions such as schizophrenia (Wamsley et al., 2012; Schilling et al., 2016). Our finding is also unexpected because practice of meditation has been associated with increased neuroplasticity (Lazar et al., 2005; Slagter et al., 2011; Kang et al., 2012), and is thought to have neuroprotective effects against cognitive decline (Gard et al., 2014) and psychopathology (Shonin et al., 2015). For instance, in one study (Pattanashetty et al., 2009) Vipassana practitioners showed no age-related decline in slow-wave sleep and REM sleep compared to controls. Our results are interpreted with caution since these exploratory analyses would not withstand error correction for multiple comparisons (e.g., the Bonferroni correction). Future work should assess sleep spindles in meditation practitioners over a whole night of sleep and with a larger sample size.

Sleep spindles have also been suggested to play a role in maintaining sleep in face of environmental stressors, especially noise (Cote et al., 2000; Dang-Vu et al., 2010, 2011; Lecci et al., 2017). Reduced sleep spindles, in addition to other markers of physiological arousal during sleep in meditation practitioners, may represent a general developed trait of increased alertness/awareness of the environment during sleep. While in normal populations sleep fragmentation may represent a pathological hyper-vigilance that may lead to insomnia and increased stress levels (Mezick et al., 2009; Dang-Vu et al., 2015) in meditation practitioners, it may not have the same negative effect due to practices that emphasize non-reactive awareness, an active monitoring of the contents of awareness, and a general increase in alertness (MacLean et al., 2010). These effects, however, tend to depend on proficiency in meditation practice: meditators in early stages of practice report more fatigue and sleepiness, while more experienced practitioners report greater alertness (Britton et al., 2014).

Brain synchronization mechanisms have been proposed to be a marker of neuroplasticity, reflecting processes of strengthening of neuronal connections and creation of new, experience-dependent, networks (Engel et al., 2001). These processes were shown to have a strong top-down attentional component (Steinmetz et al., 2000). Long-term meditation practitioners generate long-distance phase-synchrony during a compassion meditation practice, and express EEG signatures different from those of controls during both active practice and the resting state (Lutz et al., 2004). This long-distance synchrony has been proposed to be a marker of cognitive integration (Lachaux et al., 1999; Varela et al., 2001), and alterations in neural synchrony patterns can be seen as markers of psychopathology (Uhlhaas and Singer, 2006). Sleep spindles involve synchronization on the level of thalamo-cortical communication in NREM sleep (Steriade and Timofeev, 2003). Recently, slow spindles were reported to be associated with brain synchrony over longer circuits, and faster spindles with more local connectivity (Zerouali et al., 2014). Thus, involvement of slow sleep spindles in procedural memory consolidation in meditation practitioners may reflect large-scale reorganization of brain connectivity – perhaps an increased efficiency of these networks – which may positively affect many cognitive skills, including memory.

Meditation practitioners, therefore, may develop a trait-like neurophysiological profile that involves both daytime and sleep changes. This trait may be similar to that of individuals with high dream recall: in a recent study we showed that increased fast but decreased slow sleep spindles correlate with dream recall frequency (Nielsen et al., 2016). The latter is a measure previously linked with higher reactivity to auditory stimuli both in wake and during sleep (Eichenlaub et al., 2014a), and with increased activity in the temporoparietal junction and medial prefrontal cortex – areas typically associated with attention and memory (Eichenlaub et al., 2014b). This finding is consistent with observations in our current study: all our participants had high dream recall, and meditators had fewer slow sleep spindles than did non-meditating controls, possibly reflecting their increased alertness in sleep.

Finally, it is possible that meditation subsumes some of the beneficial functions of sleep. While meditation practice is generally associated with increased self-reported well-being, health and life quality, during intensive meditation practice, e.g., a meditation retreat, meditators require less sleep (Kornfield, 1979), and exhibit physiological arousal signs, such as increased gamma coherence during slow wave sleep (Ferrarelli et al., 2013). And while sleep plays an important role in memory consolidation, restful wakefulness (as opposed to active wakefulness) also promotes learning (Brokaw et al., 2016). It is possible, therefore, that daytime meditation practice is sleep-like in nature and thus reduces sleep pressure and alter subsequent sleep architecture.

Limitations

Due to the exploratory nature of this study, these results need to be interpreted with caution. The study design has three important limitations. First, we did not have a waking control group to test whether the Wii Fit task has a sleep-dependent component. The WiiFit task was selected because, unlike most traditionally used procedural tasks (e.g., finger tapping or rotor pursuit), it involves the whole body as opposed to just hand-eye coordination. Despite the lack of control group, our results indicate that in non-meditators, the task was associated with REM sleep duration – a finding well in line with much research on sleep-dependent consolidation of procedural memory. Second, some of the sleep differences between meditators and controls could be attributed to the fact that our meditators spent 10 min in meditation before bedtime, and that we did not have a group of meditators who did not meditate or controls who meditated. Vipassana meditators are encouraged to practice for 1 h every day. Thus, a 10-min session before bedtime was chosen to make sure that all meditators practiced before bedtime in the laboratory, ensuring that everyone in that group has some amount of practice on that day (including individuals who prefer to meditate in the evening/during the day). In addition, even if sleep differences could be influenced by meditation just before bedtime, group differences in the relationship between sleep architecture and learning in meditators and controls cannot be explained just by a very short meditation practice prior to bedtime.

Lastly, many of our comparisons (group comparisons for spindle density and correlations between task performance and sleep characteristics) would not survive conservative error correction, such as Bonferroni correction. In addition, the observed relationship between fast occipital spindles and task improvement in meditators was a trend ($p < 0.1$). Our project is an exploratory study, first of its kind, comparing sleep-dependent procedural learning in meditators and controls. The comparisons used (both multiple t-tests and correlations) were inherent to the study design and were planned in advance. It has been suggested that applying conservative error corrections in exploratory studies with planned comparisons may erase theoretically relevant effects (Perneger, 1998; Armstrong, 2014). Further, recent debate regarding an overreliance on p values (see recent issue of *The American Statistician*, Wasserstein et al., 2019), brought to question the wisdom of current practices that typically use p values for making dichotomous decisions regarding group differences. It has been proposed that effect size or confidence interval measures should supplement p values in making a decision on whether or not study results warrant further attention. In our study, the selective significant group differences in occipital spindles had a small to medium effect size, and magnitude of correlations between occipital spindle density and performance on the task was also moderate. Further research is needed to characterize sleep microarchitecture of meditation practitioners, and to elucidate potential changes in neurobiological substrates of motor learning associated with meditation practice.

CONCLUSION

The relationship between improvement on a full-body procedural task and sleep architecture was distinctly different between meditators and controls. In meditation practitioners, task improvement was correlated with occipital spindle density in N2 sleep but not with the duration of any sleep stages; whereas in controls, task improvement was associated with increased time in REM sleep, but not with N2 sleep spindles. Both patterns of sleep changes have been observed in prior research although never linked differentially to meditation experience as in the present study.

Our finding of different patterns of sleep-dependent memory consolidation for meditating and non-meditating controls can be accounted for by at least two explanations. On the one hand, the body-focused practices of meditation may contribute to large-scale changes in learning, including changes in sleep microarchitecture and sleep-dependent memory consolidation. On the other hand, similarities between meditation practice and habitual napping may confer additional sleep-related or sleep-like advantages to meditators.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Sacre-Coeur Hospital IRB. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ES and TN led the design of the study, data collection, analysis, and interpretation. ES was the lead writer of the manuscript. SD, AS-R, CB-C, and MC collected data. ES, SD, AS-R, and TP conducted spindle and task analyses. DS contributed to editing, manuscript writing, and revision.

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Ill-Defined Problem Solving Does Not Benefit From Daytime Napping

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The main goal of the present study was to explore the role of sleep in the process of ill-defined problem solving. The results of previous studies indicate that various cognitive processes are largely dependent on the quality and quantity of sleep. However, while sleep-related memory consolidation seems to be well-grounded, with regard to the impact of sleep on problem solving, existing research yields mixed and rather inconclusive results. Moreover, this effect has been mainly tested using simple and well-defined, common laboratory problems, such as the remote associate test (RAT), crossword and anagram puzzles, numeric and logic problems, etc. What is lacking is research on the effect of sleep on solving more complex and more real-life oriented ill-defined problems. In the present study, we hypothesized that sleep can improve performance in solving this kind of problems. The study involved 40 participants, randomly assigned to two experimental conditions: sleep group and waking group. The experimental protocol comprised three stages: problem presentation, retention interval, and testing stage. The problem was presented to the participants in the form of an interactive computer game concerning a complex, elaborate crime story. During the retention interval, the participants—depending on the condition—took a nap or stayed awake; sleeping participants underwent polysomnography recording, while waking participants performed activities not related to the experimental problem. In the testing stage, participants tried to solve the presented problem. The solutions generated were assessed both for quality (reasonableness, consistency, and story recall) and creativity (fluency, flexibility, originality, and elaboration). Contrary to expectations, we found no effect of sleep on ill-defined problem solving. Neither quality nor creativity of the solutions generated by the participants was higher in the nap group than in the waking group. There were also no performance improvements with regard to any sleep stage or incidence of dreams. Our study adds to a growing body of evidence that sleep probably might provide an incubation gap, but not a facilitating environment serving the purpose of problem solving, at least with regard to ill-defined problems.

Keywords: nap, sleep sleep/wake cognition, problem solving, ill-defined problems, divergent thinking, creative reasoning

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INTRODUCTION

The results of previous research indicate that sleep is essential for many cognitive processes. It has been repeatedly demonstrated that sleep loss or insufficient sleep is related to cognitive decline and can adversely affect a variety of cognitive and emotional abilities, including alertness, vigilance, and attention, emotional intelligence and stress management skills, memory and learning, fluid intelligence, executive functions, reasoning, and problem solving (e.g., Linde and Bergström, 1992; Fairclough and Graham, 1999; Drummond et al., 2000; Williamson and Feyer, 2000; Diekelmann et al., 2008; Killgore et al., 2008; Kronholm et al., 2009; Nebes et al., 2009; Johnston et al., 2010; Lim and Dinges, 2010; Frings, 2011; Horne and Moseley, 2011; Plessow et al., 2011; Xu et al., 2011; Jackson et al., 2013).

Sleep appears to be critical particularly for memory consolidation—a growing body of evidence shows that sleep contributes to stabilization of information acquired before sleep (Gais and Born, 2004; Stickgold and Walker, 2005; Diekelmann and Born, 2010; Conte and Ficca, 2013; Rasch and Born, 2013). This effect was found both for procedural and declarative memory (Stickgold et al., 2000; Mednick et al., 2002, 2003; Walker et al., 2003; Alger et al., 2010; Wamsley et al., 2010b; Antony et al., 2012; Payne et al., 2012; Cousins et al., 2019), and it is believed to be a result of reactivation and stabilization of recently encoded memory representations in different sleep stages (Gais and Born, 2004; Diekelmann and Born, 2010; Lu and Göder, 2012; Antonenko et al., 2013; Rasch and Born, 2013; Llewellyn and Hobson, 2015).

However, the effect of sleep seems to go beyond only a simple replay of memories. There is accumulating evidence suggesting that sleep-related memory consolidation helps to reorganize and integrate memories with preexisting knowledge, which may enhance the abstraction of underlying rules and associations. Thereby, complex cognitive processes, such as reasoning, insight, problem solving, and creativity may benefit as well (Llewellyn, 2016; Chambers, 2017). As demonstrated by Lau et al. (2011), sleep enhances the reorganization of discrete memory traces into flexible relational memory networks. Djonlagic et al. (2009) found a sleep-dependent improvement in categorizing objects, and Nieuwenhuis et al. (2013), using an artificial grammar learning paradigm, reported that classification performance improved after sleep. It was also demonstrated that sleep facilitates generation of false memories in the Deese, Roediger, and McDermott (DRM) false memory paradigm (Diekelmann et al., 2010). These findings suggest that sleep plays a critical role in integrating memories, extracting rules, creating connections, and semantic generalization of newly encoded information.

Sleep was also demonstrated to inspire insight and enhance problem solving. In the study conducted by Wagner et al. (2004) with the number reduction task (NRT), more than twice as many subjects gained insight into the hidden rule after a night of sleep as after a respective period of wakefulness. Sleep-related insight was confirmed in numerous studies (e.g., Yordanova et al., 2010; Yordanova et al., 2012; Debarnot et al., 2017). Similar results were obtained by Beijamini et al. (2014), who found that, after a nap, subjects were almost twice as likely than after waking interval to solve a video game problem involving logical reasoning. Monaghan et al. (2015) exploited analogical problems, which require applying a known solution from one problem to a related problem, and they showed that sleep facilitated such analogical transfer mainly due to structural generalization across problems. In another study (Sio et al., 2013), using a set of remote-associate tasks (RAT) varying in difficulty, sleep enhanced solving difficult problems, while there was no effect for easy problems. In line with these findings, sleep turned out to be beneficial to creativity assessed with classical measures like the abbreviated torrance test for adults (Drago et al., 2011) or the unusual uses task (Ritter et al., 2012).

These benefits of sleep are mostly connected with slow-wave sleep (SWS; Yordanova et al., 2010, 2012; Beijamini et al., 2014) and rapid eye movement (REM) sleep (Walker et al., 2002; Cai et al., 2009; Djonlagic et al., 2009; Sterpenich et al., 2014); although Drago et al. (2011) found correlations of creativity not only with stage 4 but also with stage 1 of non-REM (NREM) sleep. Similarly as in sleep-dependent learning, the mechanism of the facilitating effect of sleep on reasoning, creativity, and problem solving is believed to be the neuronal memory reprocessing during sleep, including reactivation, integration, and restructuration of new memory representations (Wagner et al., 2004; Yordanova et al., 2010, 2012; Chambers, 2017). According to the information overlap to abstract (iOtA) model proposed by Lewis and Durrant (2011), cognitive abstraction is based on an overlapping replay of newly encoded memories during slow-wave sleep, which leads to the integration of newly learned information into existing cognitive schemata, as well as to the abstraction of the gist, and thus to the formation of new schemata. Likewise, Lewis et al. (2018) propose that abstracting rules from corpuses of learned information is possible owing to memory replay mechanisms in non-REM sleep, while novel associations may be formed as a result of replay in REM sleep. Thus, it is the iterative interleaving of REM and non-REM sleep across a night that is thought to boost the formation of complex knowledge frameworks. This mechanism allows to recombine and restructure memories, facilitating creative thinking.

A number of studies suggest also a possible relationship between cognition and dreaming. According to Payne and Nadel (2004), dreaming reflects long-term memory consolidation, which strengthens the neural traces of recent events, integrates new traces with existing memories and prior knowledge, and sustains their stability. In a study by Wamsley et al. (2010a), improved performance at retest in a virtual navigation task was indeed strongly associated with task-related dream content during an intervening afternoon nap, while task-related thoughts during respective period of wakefulness did not yield any improvement. These findings support the view that dream experiences reflect the offline reactivation of recently formed memories during sleep. In line with this model, Fogel et al. (2018) demonstrated that the extent to which some novel experiences are learned is related to the extent to which these experiences are incorporated into the dream content, while the extent of this incorporation is related to interindividual differences in cognitive abilities. Dreams are also thought to inspire creativity and problem solving (Barrett, 2001a,b; Llewellyn, 2016). For instance, it turned out that musicians dream about music more often than non-musicians and that the music from their dreams is often novel and original (Uga et al., 2006). Likewise, film makers more often than the general population report that dreams affect their creative activity (Pagel et al., 1999). In two questionnaire studies involving ordinary people, the majority of participants reported experiencing sleep- or dream-related insights occasionally or regularly, and many admitted that these stimulating dreams played a considerable role in their lives (Schredl and Erlacher, 2007; Perdomo et al., 2018). In another study (Barrett, 1993), participants were instructed to incubate dreams addressing problems of their own choice. About half of them recalled a dream that they judged as related to their problem; moreover, a majority of these dreams were believed to contain a problem solution.

Nevertheless, there are also some contradictory evidence, undermining the effect of sleep on problem solving. In one of the first laboratory studies on this issue, Cartwright (1974) did not find any improvements in the performance on intellectual tasks after sleep compared to wakefulness. In another study, Landmann et al. (2016) used the compound remote associate (CRA) task, which is a verbal creativity task, and reported sleep-related improvements in strengthening, but not in the creative reorganization, of newly encoded memories. As reported by Debarnot et al. (2017), sleep facilitates insight in problem solving only in young adults, while in old adults, no sleep-dependent improvement in problem solving was observed. Two recent studies corroborated these results. Schönauer et al. (2018) found no effect of sleep on the solution of classical insight problems or magic tricks. Neither general solution rates nor the number of solutions accompanied by sudden subjective insight were influenced by a nap compared to waking period, and no significant correlations between performance and the time spent in specific sleep stages were obtained. This findings were supported in another study by Brodt et al. (2018), who demonstrated that an incubation period positively affected solution rates in classical riddles; however, spending the period of incubation asleep yield no additional benefit. These results suggest that sleep might not be facilitating for problem solving in general, or for solving particular problems, and that at least some of the sleep-related improvements in complex cognitive processes might be a result of incubation rather than sleep itself.

To summarize, although there is a growing body of research on the impact of sleep on problem solving, their results are still rather inconclusive. Moreover, this effect has been mainly tested using simple and well-defined, common laboratory problems, such as the RAT and analogical problems (Cartwright, 1974; Cai et al., 2009; Sio et al., 2013; Monaghan et al., 2015), crossword and anagram puzzles (Cartwright, 1974; Walker et al., 2002; Brodt et al., 2018), numeric and logic problems (Wagner et al., 2004; Yordanova et al., 2010; Beijamini et al., 2014; Brodt et al., 2018), or standard paper-and-pencil tests (Cartwright, 1974; Drago et al., 2011; Ritter et al., 2012). This kind of clearly structured problems are off course easily brought into the psychological laboratory. However, there is some concern that such tasks may not appropriately capture real-world cognitive functioning and problem solving, since problems frequently encountered in the real world, such as political, economic, science, societal, moral, or personal problems, as well as daily life problems, are often much more complex and mainly ill structured. What is lacking thus is research on the effect of sleep on solving more complex and more real-life oriented ill-defined problems which feature open boundaries and have no well-determined solutions. Along with life-long learning and collaboration skills, solving complex, ill-defined problems is believed to be one of the most important competencies in the modern world, and it is particularly important to study how people deal with complex, dynamic, and uncertain real-world challenges (Jonassen, 2000; Greiff et al., 2014; Shute et al., 2016; Dörner and Funke, 2017). Given that well- and ill-defined problem solving are independent to a large extent and require separate cognitive processes (Schraw et al., 1995; Welter et al., 2017), we can suppose that the effect of sleep might be different in these two types of problem situations.

Well-defined (well-structured) problems are those that contain a clear specification of three elements of the problem space: the initial state (the problem situation), the set of operators (rules and strategies) to solve the problem, and the goal state (the solution). Ill-defined problems lack all or most of the information required to reach a solution, i.e., they leave at least one of the three elements (initial state, solution operators, or goal state) not clearly specified (Reitman, 1965; Newell and Simon, 1972; Eysenck and Keane, 2000). Well-defined problems tend to have a single, convergent, absolutely correct, and knowable solution, while ill-defined problems often, apart from offering incomplete, ambiguous, open to interpretation, or uncertain initial states and sets of operators, may be solved with a multitude of potentially effective solutions (Kitchener, 1983; Simon, 1986; Moreau and Engeset, 2016). Solving an ill-defined problem often involves exploration and experimentation along with developing, evaluating, and selecting a solution from a set of multiple ideas generated in the course of the problem solving process (Guilford, 1967/1978; Dörner and Funke, 2017), and the cognitive abilities required for ill-defined problem solving are comparable to those required for creativity tasks (Welter et al., 2017). Solving an ill-defined problem can be thus considered as an act of creative thinking (Moreau and Engeset, 2016). Nevertheless, creativity or divergent thinking is not sufficient to solve ill-defined problem. The solving process must be eventually brought to an end—the set of generated possible solutions must be narrowed, and each of the solutions has to be valued with respect to their quality and functionality in the context for which they were intended. This involves also convergent thinking, and thus, both convergent and divergent thinking processes intertwine and cooperate to reach a viable solution of an ill-defined problem in a process called creative reasoning: Divergent thinking is responsible for creating new ideas, while convergent thinking ensures correct and logical assessments and choices (Cropley, 2006; Jaarsveld et al., 2010). Therefore, when investigating ill-defined problem solving, it seems reasonable to take into account both efficacy, or quality, and creativity of the solution.

The main goal of the present study was to test the possible effect of sleep on the process of ill-defined problem solving. In line with some previous findings, we hypothesized that sleep can improve performance in solving ill-defined problems. In the present study, a nap paradigm was adopted. It has been demonstrated repeatedly that a short daytime nap may yield similar memory or reasoning improvement as an overnight sleep. Concurrently, it allows to avoid confounds by sleep–wake cycle and sleep deprivation of participants (Mednick et al., 2003; Lahl et al., 2008; Beijamini et al., 2014; Payne et al., 2015). In the present study, the experimental protocol comprised three stages. First, participants were acquainted with a complex, ill-defined problem, which they tried to solve after a retention interval filled with sleep (90 min nap) or wakefulness. We expected that nap participants would solve the problem more efficiently and more creatively. We also explored if dreams could benefit problem solving, i.e., if participants' performance is related to the incidence of dreams or dream content.

MATERIALS AND METHODS

To test the feasibility of methods and procedures, a pilot study was conducted first; then, some corrections were applied to the main study protocol and research tools. Subsequently, the main study was conducted. Owing to the changes introduced to the study procedure, it was not possible to include the results of the pilot study in the final analyses. However, some preliminary analyses of the mere pilot study findings were also conducted. Detailed results of the pilot study followed by the modifications of the study protocol implemented after the pilot study are presented in **Supplementary Material**.

Participants

Participants were recruited by internet advertisements and then qualified to the study on the basis of the screening test. Exclusion criteria were neurological or psychiatric disorders, the use of sleep-affecting or nervous-system-stimulating drugs, and inability to sleep during the day. Overall, 134 individuals filled out the screening test, and 88 individuals who met the inclusion criteria were invited to take part in the study. Eventually, 40 participants came forward and finished all the steps of the study, 31 female and 9 male, aged 19–35 (mean age, 23.3). Participants were students of various programs or had higher education (16 participants were studying psychology or had a psychology degree). They were financially compensated for their participation. Additionally, 20 participants took part in a pilot study (see **Supplementary Material**).

The participants were randomly assigned to two experimental conditions: sleep group and waking group. One sleep participant was excluded due to some abnormalities in the PSG recording and suspicion of sleep disorder, leaving a total of 39 participants for analysis (19 in the sleep group, 14 female and 5 male; 20 in the waking group, 16 female, 4 male).

Procedure and Measures

Screening

The screening test, used during the recruitment process, included questions concerning main exclusion criteria (neurological or psychiatric disorders, the use of sleep-affecting or nervous-system-stimulating drugs, and inability to sleep during the day). Additionally, it covered basic demographic and health variables, sleep patterns and sleep quality, as well as experience with computer games and crime stories and riddles (books, films, etc.).

One week before the experimental day, participants selected for the study were invited to the laboratory to take the APIS-Z battery (Ciechanowicz et al., 1995)—a multidimensional standardized paper-and-pencil test commonly used to assess general intelligence. APIS-Z is designed especially to assess intelligence in students and persons with higher education. It comprises of eight tests, measuring four types of cognitive abilities: abstract–logical, verbal, visuospatial, and social abilities. It has high internal consistency for the total score and satisfactory stability and validity. In the present study, only the total IQ score was taken into account to control the influence of this variable on participants' performance. Participants were also informed in detail about all the experimental procedures and study goals and instructed to abstain from caffeine and sleep-affecting drugs directly before the study. Then, they were asked to keep sleep logs for a week before the study to monitor their sleep–wake cycle. The following variables were considered for further analysis: average sleep time, average sleep onset and average wake-up time, sleep onset the night before the experiment, wake-up time on the day of the experiment, and sleep time the night previous to the experiment.

Experimental Protocol

Following the screening process, participants took part in the main, experimental part of the study. Upon arrival at the laboratory at 11:00 AM, participants were informed in detail about all the experimental procedures and instructions and randomly assigned to experimental condition. The experimental protocol comprised three stages: problem presentation, retention interval, and testing stage. The problem was presented to the participants in the form of an interactive computer game concerning a complex, elaborate crime riddle. Participants played the game for 60 min. During the retention interval, the participants—depending on the condition—took a 90-min nap or stayed awake. Sleeping participants underwent polysomnography recording, while waking participants performed activities not related to the experimental problem (they watched nature documentary videos). In the testing stage, all participants played the game for another 40 min and then took the final test, comprising questions concerning the presented problem. The experimental design is schematically presented in **Figure 1**.

Behavioral task

The experimental problem was presented to participants in the form of the interactive video game *Her story*.[1] As demonstrated, using computer games not only allows to create a situation of more interactive nature, which may facilitate motivation to struggle with the experimental problem (Przybylski et al., 2010) but also allows to reconcile designing complex and real-world problem situations with methodological requirements of laboratory experiments (Wouters et al., 2013).

In the game used in the present study, the player searches and sorts through a database of video clips from fictional archived

[1] www.herstorygame.com

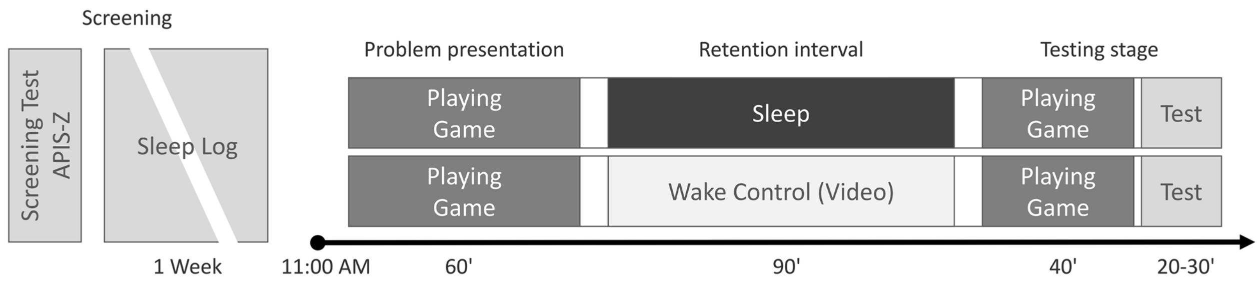

FIGURE 1 | Study protocol. One week before the experimental day, participants filled out the questionnaires (screening test and APIS-Z battery) and started sleep log. On the experimental day, they were acquainted with the problem in the form of a computer game first; then, they took a nap (sleep group) or watched videos (waking group). In the testing stage, participants finished the game and tried to solve the problem (filling out the final test).

police interviews and uses the clips to solve the case of a murder. The interviews are unable to be watched in their entirety or in proper, chronological order; only fragmented short clips are available. Furthermore, merely answers of the interrogated person can be heard, while the questions of the off-screen detective remain unknown. The player takes on the role of the person sitting before a police computer terminal, attempting to solve the case by piecing together information, like in a real police investigation; and like in a real investigation, the objective is uncertain—the player gets only vague instruction to "resolve the case" and does not exactly know what is the overriding goal and successive steps to take. Moreover, the game does not have a classical end ("win/lose") and a definitive solution, so the whole story might be variously explored and interpreted.

Participants were not provided with any background information before playing. The instruction was as follows: "*You will play a computer game now. Your task is to solve a complex problem, a sort of criminal case. You will play the game for an hour.*" If participants asked for more information, both before and during playing the game, they were only instructed: "*try to acquire as much information as you can, to resolve the case*," and if they kept asking, they were informed: "*it is your task to find the solution on your own, so the experimenter cannot advise anything*." The game mechanics is very simple, and it resembles the google search engine—the player just thinks up keywords and types them in the browser pane; then, the database returns clips where the interrogated person speaks those words. In the beginning of the game, the player sees an old-school computer desktop with the database activated, and the word "murder" entered in the browser pane. When the player clicks "search," first few clips can be seen. Then, after watching those first clips, the player can search the database using other words that he/she expects to bring some more information about the case. There are almost 300 clips—shorter or longer, and including key information for the case or just less important, marginal threads—therefore, the player has to carefully choose the keywords to get to the most informative and interesting clips. Some screenshots and videos from the game are available from the producer's website.

This game was chosen due to its non-linear storytelling, open to interpretation and fragmented narrative, uncertain goal state and vague means of achieving it, as well as ambiguity and the lack of a definitive solution. Solving the problem presented in the game requires exploring and analyzing a large amount of information including conflicting assumptions and evidence, identifying problems, and planning of successive steps. Because the story is complex and multithreaded, the problem definition must be changed dynamically as the player discovers subsequent facts. This kind of problem fits the definition of ill-defined problem (Reitman, 1965; Newell and Simon, 1972; Kitchener, 1983; Simon, 1986; Eysenck and Keane, 2000). Given that complex problem solving is often dependent on prior knowledge and on emotional and motivational processes (Dörner and Funke, 2017), a crime riddle was chosen because it seems to be quite common and universal, as well as interesting, attracting, and motivating for participants, due to its interactive form and intriguing plot.

Polysomnography recording

In-laboratory sleep recordings were performed in accordance with standardized techniques, using a Comet PSG system (Grass Technologies). Electroencephalogram (EEG) (from scalp locations: F3, F4, C3, C4, O1, and O2, according to the 10–20 system), electrooculogram (EOG) (from the left and right outer canthi of the eye), and electromyogram (EMG) (from the chin muscles) were recorded with gold-plated cup electrodes applied to the skin. EEG and EOG channels were referenced to the contralateral mastoids (M1 and M2); the EMG channel was recorded as a bipolar derivation. The ground electrode was placed on the forehead (Fpz). Electrode impedances were lower than 5 kΩ. All participants from the sleep group were permitted a 90-min opportunity within the retention interval to attempt napping, and after 90 min, they were awakened regardless of the sleep stage they were in. After the nap, participants were also asked if they had any dreams.

Sleep stages were visually scored in 30-s epochs by a single expert in accordance with the Manual for Scoring from American Academy of Sleep Medicine (Berry et al., 2015) using TWin software (Grass Technologies). Scoring was performed blind to participants' behavioral task performance. The following variables were taken into account for further analysis: total sleep time, particular sleep stages time (N1, N2, SWS, and REM), sleep latency, wake after sleep onset (WASO), and the number of dreams. Dream content was analyzed with regard to the incidence of incorporations of the presented problem by a single expert blind to participants' behavioral task performance.

Testing stage

In the testing stage, participants tried to solve the presented problem. First, they played the game and could explore the problem for another 40 min. Then, they took the final test. Because the problem presented in the game does not have one specified solution and the game does not have a classical end ("win/lose"), it is not possible to apply usual "correct/false" indicator to assess if the participant solved the problem or not. Therefore, a more complex procedure was used to measure participants' performance, consisting in a paper-and-pencil test scored by a panel of expert raters. The test was prepared particularly for the purpose of the present study and revised after the pilot study (see **Supplementary Material** for details)—vague or suggesting questions were modified or removed, and some questions were added or expanded to allow obtaining more elaborate and detailed responses, which might more clearly reveal participants' reasoning process. New scoring rules were also prepared.

Finally, the test included 38 open questions concerning both the facts from the game (18 questions, e.g., "Did Simon have an affair?," "Where was Simon's body found?," "Who got a mirror from Simon?," "What alibi did the interrogated woman present?" etc.) and participants' conclusions and interpretations of the story (20 questions, "When and why did the interrogated woman change her testimony?," "Who killed Simon? Why was he killed?," "What role did a mirror play in the whole story?," "Do you think that the interrogated woman lied? When?," "Which threads of the story do you consider most important in the view of the investigation?," "What might have happened after the last interrogation? What might be the next step of the police in the case of Simon's murder?" etc.). Time for filling out the test was not limited; it usually took approximately 20–30 min.

Four independent expert raters, blind to participants' group assignment, assessed the solutions generated by the participants for their quality (how effectively the participant solved the problem) and creativity (how creative the solution was). Quality of the solution was assessed with respect to three criteria: reasonableness, consistency, and story recall. Creativity of the solution was assessed with respect to four classical criteria, proposed by Guilford (1967/1978) and Torrance (1974): fluency, flexibility, originality, and elaboration. Scores for each of the criteria were summed for each rater and then averaged.

Reasonableness refers to validity and pertinence of the solution. Although the presented problem does not have a simple solution and the story might be variously interpreted, careful investigation of all the facts shows that some explanations are more and some are less probable and justified. The reasonableness scale measures the convergence of participants' interpretations with this most probable solution. Participants' answers were scored with 0 points (invalid or no answer), 1 point (valid, but not profound and insightful answer), or 2 points (valid and profound, insightful answer, logical and well-grounded in the context of the whole story, not only a single thread or situation). All the questions were included in this score, and the scores for each answer were summed up; therefore, the minimum score for this scale was 0, and the maximum was 76 points (the more points, the more reasonable the solution was).

Consistency is a measure of the coherence of the solution, i.e., consistency of responses to different questions. All the questions were included in this score, and the raters assessed if the answers compose a logical plot—first, the raters read answers to three key questions provided by the participant to initially qualify his/her interpretation of the story, and then, they assessed each answer with respect to its consistency with the participant's interpretation. Participants' answers were scored with 0 points (no answer), C (answer consistent with the participant's interpretation), P (answer only partly consistent with the participant's interpretation), or I (answer inconsistent with the participant's interpretation). The result in this scale was the ratio of the consistent answers to all answers (all responded questions): $(C + 0.5 P)/(C + P + I)$. This kind of index was used here instead of the sum to avoid the missing-responses bias (participants with many missing responses, i.e., those who answered only few questions but all their answers were consistent would have lower scores than participants who answered all the questions but in an inconsistent way). The minimum score for this scale was 0 points, and the maximum was 1 point (the closer the score to 1, the more consistent the solution was).

Story recall refers to the number of properly recalled facts from the game. Unlike the reasonableness score, in this scale, participants' answers were assessed with respect to the basic knowledge of isolated facts, not the whole picture of the plot. However, due to the task specificity, probably not all participants acquired all the facts because they had not watched all the key clips. Therefore, this score plausibly depends also on participants' ability to effectively search and sort information and to solve the problem, being not exclusively a memory indicator. It is partly a measure of the amount of information participants have reached to, not the amount of information they have recalled from the information they were presented. The answers were scored with 0 points (incorrect or no answer), 1 point (correct, but perfunctory, not detailed answer), or 2 points (correct and detailed answer). Four questions impossible to respond unequivocally on the basis of the game (questions concerning some additional interpretations, further course of events, etc.) were excluded from this score. The scores for each answer were summed up; thus, the minimum score for this scale was 0, and the maximum was 68 points (the more points, the better recall).

Fluency refers to the number of solutions. Participants' answers were scored with 0 points (incorrect or no answer), 1 point (any relatively correct, single answer), or 2 points (two or more probable and anyhow justified explanations). All the questions were included in this score, and the scores for each answer were summed up; thus, the minimum score for this scale was 0, and the maximum was 76 points (the more points, the more fluent the solution was).

Flexibility is a measure of the diversity of solutions. If an answer included more than one probable and justified explanation, these explanations were assessed with respect to their similarity. Each answer was scored with 0 points (single or no answer), 1 point (two or more similar explanations), or

2 points (two or more different explanations). Four questions that may have been responded only in one way were excluded from this score. The scores for each answer were summed up; therefore, the minimum score for this scale was 0, and the maximum was 68 points (the more points, the more flexible the solution was).

Originality refers to the rarity and unusualness of the solution. Participants' answers were scored with 0 points (typical answer) or 1 point (rare, original answer, submitted by only one or two participants; all original responses were taken into account; therefore, if more than one original response for one question was submitted, more than one point was scored). All the questions were included in this score, and the scores for each answer were summed up, the minimum score for this scale was 0, and the maximum theoretically was not limited due to the fact that participants could get more than one point for each answer (the more points, the more original the solution was).

Elaboration refers to the effort put in developing the solution, i.e., the number of words or details in the description, regardless of its correctness. The answers were scored with 0 points (no answer), 1 point (short, single answer), 2 points (longer, more elaborate answer including some additional details), or 3 points (exhaustive, comprehensive description). All the questions were included in this score, and the scores for each answer were summed up; therefore, the minimum score for this scale was 0, and the maximum was 114 points (the more points, the more elaborate the solution was).

Statistical Analyses

Kendall's coefficient of concordance (W) was performed to measure agreement among the four raters who scored the problem solutions generated by the participants in the final test. To test the effect of sleep on participants' performance, independent t-tests were used, adjusted for multiple comparisons with the sequentially rejective multiple-test procedure (Bonferroni–Holm correction; Holm, 1979). Some additional independent t-tests and χ^2 together with regression analysis were used to assess possible relationships with other factors.

RESULTS

To test the agreement among the four raters who assessed participants' solutions, Kendall's coefficient of concordance was calculated. The obtained coefficients were high for reasonableness, story recall, fluency, flexibility, originality, and elaboration, and lower, but still acceptable, for consistency (see **Table 1**). Therefore, the raters' scores were averaged, and those aggregated scores were used in further analyses.

To test the effect of sleep on problem solving a number of pairwise comparisons (t-tests for independent samples, adjusted for multiple comparisons) was conducted to compare the performance of sleep and waking participants. None of the effects was significant. The results are presented in **Table 2**, and **Figure 2** shows box-and-whisker plots for all the effects. There was also no effect with regard to any sleep stage or incidence of dreams. The nap architecture, obtained by PSG, is shown in **Table 3**. All participants from the sleep group actually fell asleep, with the shortest nap lasting for 10.5 min and the longest for 82 min; 16 participants had achieved slow-wave sleep, and 7 had achieved REM sleep. Moreover, 13 participants recalled dreams, although their content was mostly very short and undetailed, and none of the dreams seemed to be related to the experimental problem.

To explore any confounding factors related to participants' performance, the demographic data and sleep patterns were analyzed. Sleep and waking groups were balanced for age, sex, IQ, and education (the distribution of participants who were studying psychology or had a psychology degree was similar between groups). There was also no difference between groups in any sleep-pattern variable (both obtained from the Screening Test and Sleep Logs) and experience with games or crime riddles (see **Table 4**). To investigate other possible factors related to the problem-solving process, some additional analyses were conducted. Multiple regression, depicted in **Table 5**, indicated that IQ and sex were strongly related to participants' performance: IQ was related to story recall, reasonableness, and fluency (the higher the IQ score, the higher the problem-solving scores), while sex was related to story recall, fluency, flexibility, originality, and elaboration (women had higher scores than men). These two variables explained for ∼40% of the variance in story recall and fluency. There was no effect for education (psychological vs. non-psychological).

DISCUSSION

In the present study, we hypothesized that, after a nap, participants would solve the problem more efficiently and more creatively than after a respective period of wakefulness. Nevertheless, the findings did not support this hypothesis. Neither quality nor creativity of the solutions generated by the participants was higher in the nap group than in the waking group. There were also no performance improvements with regard to any sleep stage or incidence of dreams. Thus, contrary to expectations, we found no effect of sleep on ill-defined problem solving. However, despite the fact that a number of studies supported sleep-related insight, reasoning, and creativity (Wagner et al., 2004; Yordanova et al., 2010, 2012; Drago et al., 2011; Ritter et al., 2012; Sio et al., 2013; Beijamini et al., 2014; Sterpenich et al., 2014; Monaghan et al., 2015;

TABLE 1 | Coefficients of concordance among the four raters' scores of participants' solutions.

	Kendall's *W*
Reasonableness	0.96
Consistency	0.42
Story recall	0.98
Fluency	0.96
Flexibility	0.91
Originality	0.79
Elaboration	0.93

TABLE 2 | Effects of sleep on problem solving.

	Sleep group (*N* = 19)		Waking group (*N* = 20)		*t*(37)	*p*
	Mean	***SD***	**Mean**	***SD***		
Reasonableness	31.8	10.76	31.5	8.57	0.122	0.903
Consistency	0.95	0.03	0.95	0.04	0.109	0.914
Story recall	33.3	6.90	32.1	7.32	0.534	0.597
Fluency	33.0	6.60	31.8	6.65	0.553	0.584
Flexibility	8.4	4.86	6.9	4.15	1.062	0.295
Originality	3.2	1.53	2.4	1.70	1.538	0.133
Elaboration	44.7	10.39	45.3	10.68	−0.170	0.866

Debarnot et al., 2017), there is also accumulating evidence that sleep does not benefit problem solving (Landmann et al., 2016; Debarnot et al., 2017; Brodt et al., 2018; Schönauer et al., 2018). Our study suits this line of research.

One possible explanation of the lack of any sleep effect in our study may be associated with sleep duration. The beneficial effect of sleep on problem solving was mainly supported in studies concerning overnight sleep (Walker et al., 2002; Wagner et al., 2004; Drago et al., 2011; Ritter et al., 2012; Sio et al., 2013; Monaghan et al., 2015), while Brodt et al. (2018) and Schönauer et al. (2018) found no such effect in their nap studies, and Cai et al. (2009) reported it only for naps that included REM sleep. Furthermore, this effect is strongly related to slow-wave sleep and REM sleep (Walker et al., 2002; Cai et al., 2009; Djonlagic et al., 2009; Yordanova et al., 2010, 2012; Drago et al., 2011). There is also some evidence that dreams might provide a mechanism that enhance problem solving (Stickgold et al., 2001; Payne and Nadel, 2004; Wamsley et al., 2010a; Nieuwenhuis et al., 2013; Llewellyn, 2016; Fogel et al., 2018). In the studies with overnight sleep, participants normally obtain several cycles of both SWS and REM sleep, and usually have several dreams, while in our nap study, admittedly, all nap participants fell asleep, but only few obtained SWS and REM sleep or recalled any dreams. In addition, considering the brevity of the nap, the duration of both SWS and REM sleep in most cases did not exceed several minutes, compared with over an hour in a usual overnight study. No clear incorporations of the presented problem into the dream content were observed as well. It is possible that this amount of both SWS and REM sleep, and the lack of problem-related dream content, was not sufficient to effectively boost problem solving. Whereas there is some evidence that nap-dependent learning is comparable to that reported for an overnight sleep (Mednick et al., 2003; Lahl et al., 2008; Payne et al., 2015), this effect seems to be limited to memory consolidation. Ill-defined problem solving apparently requires either different resources not related to sleep, or longer sleep. Nevertheless, this assumption is not easy to reconcile with the results of Beijamini et al. (2014), who confirmed the sleep-related problem solving effect in a 90-min nap study with only few minutes of both SWS and REM sleep. This discrepancy might be a result of the tasks used. Both studies exploited video games; however, while Beijamini et al. (2014) used a simple logic task, we instead attempted to arrange a real-life situation and address ill-defined problem solving, using a complex and ambiguous crime riddle.

The results of our study may indicate that certain tasks profit more from sleep than others and, consequently, that certain cognitive processes benefit from sleep and others do not. As discussed by Lerner and Gluck (2019), the facilitating effects of sleep on the abstraction of hidden regularities within newly encoded stimuli strongly depend on the task specifics. Similarly, this might be the case with complex cognitive processes, i.e., the effect of sleep on problem solving might vary depending on the task used, and thus the cognitive processes involved. Whereas Beijamini et al. (2014), using a video game, demonstrated that sleep may promote the solution of problems

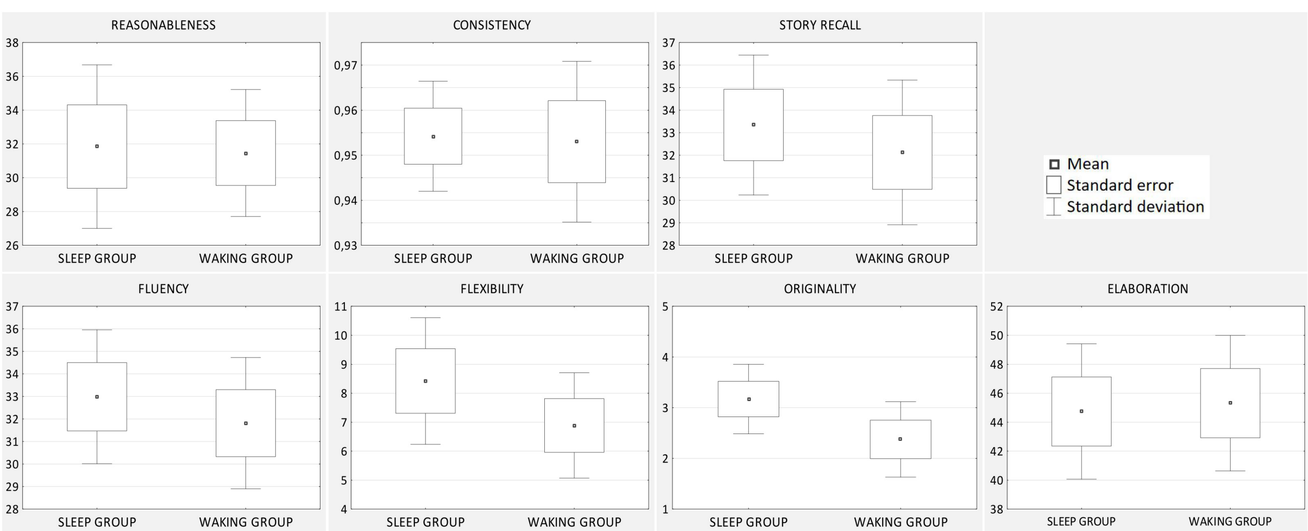

FIGURE 2 | Effects of sleep on problem solving. Differences between sleep and waking group in task performance (means, standard errors, and standard deviations).

TABLE 3 | Nap architecture.

	Sleep duration (minutes)				N
	Mean	SD	Min	Max	
TST	53.08	23.16	10.50	82.00	19
N1	13.42	6.23	3.00	29.00	19
N2	22.39	11.49	4.00	42.00	18
SWS	16.81	17.50	0.50	53.00	16
REM	11.64	2.76	7.00	14.50	7
WASO	22.92	19.97	2.50	71.50	19
Sleep latency	14.03	10.70	2.50	36.50	19
Number of dreams	1.15	0.38	1.00	2.00	13

that involve logical reasoning, no sleep-dependent improvement was observed in solving classical insight problems and magic tricks (Schönauer et al., 2018), as well as classical riddles (Brodt et al., 2018). Likewise, there is some evidence that sleep inspires insight and enhances problem solving in the NRT (Wagner et al., 2004), analogical problems (Monaghan et al., 2015), or the remote associate task (Sio et al., 2013), while Landmann et al. (2016) found no effect of sleep on creative reorganization of newly acquired memory traces in the compound remote associate task. In the present study, an interactive video game concerning a complex, elaborate crime riddle was used to address the process of solving a complex and real-world ill-defined problem. This kind of task requires much more complex cognition than simple memory reactivation that can be enhanced by sleep. In ill-defined problem solving, convergent thinking intertwines with divergent thinking, and this intertwining, called creative reasoning, may be defined as the ability to generate original, yet appropriate, solutions (Jaarsveld et al., 2010; Moreau and Engeset, 2016; Welter et al., 2017). It is largely independent from well-defined problem solving (Schraw et al., 1995; Jaarsveld et al., 2010) and requires advanced restructuring of problem representations and identifying connections, as well as reorganization and recombination of preexisting knowledge in a non-obvious way to generate new knowledge (Eysenck and Keane, 2000; Llewellyn, 2016). The results of our study do not support a notion that these processes benefit from sleep and that sleep-related memory consolidation might enhance this kind of problem restructuring and the recombination of knowledge elements necessary for ill-defined problem solving. It is possible that sleep provides only a period of brain isolation reducing interfering stimulation, which might yield comparable benefits for problem solving as a waking incubation interval (Wixted, 2004). Future studies are needed to further test if spending the incubation period asleep provides any additional improvements in solving different kinds of problems.

It is also possible that with regard to complex and ill-defined problem solving, sleep facilitates mainly the solution of personal problems. As demonstrated by Barrett (1993), problems of a personal nature were more likely to be viewed as solved after dream incubation than academic or general problems. In the present study, we used an intriguing, but rather "intellectual" problem, not related to any personal concerns. It is probable that participants did not engage in playing to such an extent as they would have if they were involved in the situation personally and that they treated the game as an intellectual pastime, admittedly interesting, attracting, and intriguing, maybe even thrilling and exciting, but not personal, and thus distantly related with their daily concerns and individually important matters. We also did not apply any task reactivation during sleep. It might be interesting to explore if a conditioned odor or auditory cue would

TABLE 4 | Sample demographics and sleep patterns.

	Sleep group (N = 19)		Waking group (N = 20)		p
	Mean	SD	Mean	SD	
Age	22.8	2.76	23.6	3.89	0.460
Sex ratio (M/F)	0.36	–	0.25	–	0.640
IQ	34.8	9.25	33.9	8.78	0.746
Education ratio (proportion of psychology students or psychologists)	0.37	–	0.45	–	0.604
Experience with computer games	1.53	1.31	1.10	0.97	0.253
Experience with crime riddles	1.95	1.03	1.50	0.89	0.153
Average sleep time (ST)	7:33	1:25	7:30	0:40	0.882
Average sleep onset (ST)	11:33 PM	2:33	0:18 AM	2:34	0.718
Average wake-up time (ST)	7:48 AM	1:05	7:36 AM	1:12	0.547
Sleep quality (ST)	3.95	0.70	4.15	0.67	0.364
Average sleep time (SL)	7:56	1:10	7:54	0:50	0.897
Average sleep onset (SL)	1:02 AM	1:00	0:07 AM	0:53	0.996
Average wake-up time (SL)	8:40 AM	1:11	7:58 AM	1:00	0.954
Sleep time the night previous to the experiment (SL)	7:39	1:13	8:00	1:24	0.671
Sleep onset the night before the experiment (SL)	0:53 AM	1:16	0:03 AM	1:06	0.969
Wake-up time on the day of the experiment (SL)	8:41 AM	1:09	8:02 AM	1:04	0.927

p-values were obtained using chi-square for the sex ratio and education ratio, and using two-sided t-tests for other variables. Sleep-pattern variables are expressed in hh:mm. ST, screening test; SL, sleep log.

TABLE 5 | Multiple regression for problem solving scores.

	Reasonableness	Consistency	Story recall	Fluency	Flexibility	Originality	Elaboration
IQ							
β	**0.46**	−0.14	**0.45**	**0.45**	0.28	0.06	0.23
t	**3.12****	−0.84	**3.52****	**3.40****	1.80	0.37	1.56
Sex							
β	0.28	0.21	**0.45**	**0.46**	**0.40**	**0.43**	**0.59**
t	1.76	1.14	**3.26****	**3.23****	**2.34***	**2.51***	**3.79*****
Education							
β	−0.03	0.05	−0.07	−0.04	0.06	−0.03	0.17
t	−0.17	0.26	−0.50	−0.24	0.36	−0.16	1.03
F	5.36**	0.75	10.71***	9.60***	3.23*	2.97*	5.70**
R	0.56	0.25	0.69	0.67	0.47	0.45	0.57
R^2	0.31	0.06	0.48	0.45	0.22	0.20	0.33
Adjusted R^2	0.26	−0.02	0.43	0.40	0.15	0.13	0.27

*Values in bold show statistically significant relationships. *p < 0.05, **p < 0.01, ***p < 0.001. β, standardized regression estimates.*

be helpful in this kind of complex, ill-defined task. Such cues were effectively used in studies on the effect of sleep both on memory (Rihm et al., 2014) and creative performance (Ritter et al., 2012; Sterpenich et al., 2014). There is also a possibility that, in the present study, the time for the initial problem exploration was too short. In a study by Wagner et al. (2004), sleep did not enhance insight in the absence of initial training. Perhaps, in the case of a complex, ill-defined problem to solve, participants should have an opportunity of longer problem exploration. Moreover, Wamsley et al. (2010b) reported that sleep facilitated performance in navigating in a virtual maze only for participants having prior experience with navigating in a three-dimensional environment. Although we controlled for participants' experience with crime riddles and computer games, and although there were neither any differences between the groups with regard to both variables, nor any relation to participants' performance, we cannot rule out entirely the possible confounding effects of participants' prior knowledge and experience. Another interesting possibility is related to the duration of the retention interval. Sleep that occurs shortly after learning is most beneficial to memory 24 h (Payne et al., 2012) or even 48–96 h after initial training (Stickgold et al., 2000). Furthermore, 30 min after learning, cramming, and napping led to similar memory improvement, but after a week, napping maintained this significant advantage, while cramming did not (Cousins et al., 2019). It is possible that considering the influence of sleep on ill-defined problem solving, also a kind of time-gap is needed for the effect to manifest. Last but not the least, the kind of video material used in the waking group might have contributed to the lack of any sleep effect. With regard to requisite task neutrality of the video material, waking participants watched a nature documentary, which was low-involving; a number of participants even assessed it as boring, and thus, they might have spent that time on pondering on the problem solution. As reported by Mooneyham and Schooler (2013), mind wandering improves creative problem solving. Therefore, in the present study, which addressed complex, ill-defined problem solving, such mind wandering might have been as helpful and beneficial as a nap. It would be noteworthy to explore the impact of various video materials in this kind of experimental situations, which might help to choose materials absorbing and task neutral at the same time.

Surprisingly, we found no differences between the groups in story recall. Because the sleep-dependent memory improvement seems to be well-established, as it was already discussed, we expected that nap participants would perform better on this measure. This effect was not observed, though. However, as already noted in *Methods*, due to the task specificity, this score was probably not exclusively a memory indicator. All the information in the game, i.e., the story plot, was presented to the participants as fragmented and disordered video clips, and the data itself were complex and ambiguous. Despite the fact that participants were given some information to memorize, acquiring that information required not only simple encoding but also prior searching and selection; thus, this measure was probably dependent not only on memory processes but also on the ability to effectively search and sort through the whole database. Furthermore, story recall was tested only once, in the end of the experimental protocol; thus the test does not allow to directly compare the effect of sleep vs. wake on memory consolidation because there was a new learning phase before the test. However, this phase was important with regard to the problem solving process—we presumed that after the nap, participants would better understand the problem situation and use better, more effective keywords that would allow to get to the most informative clips and better explore the problem and therefore would help to solve it. It was not possible to test story recall directly after the retention interval because it might have suggested some keywords, and problem solution, to the participants. Presumably, neither did this measure address pure recall, but rather the effectiveness of solving the problem, and also this result seems to be in line with our general findings, suggesting that sleep does not enhance solving ill-defined problems. Another limitation of the study is the fact that the creativity measures used in the task might be biased by the amount or quality of information that participants were able to gather (e.g., how many clips they watched or how informative the watched clips were) and probably do not capture solely creative processes. In future research, it would be noteworthy to prepare the protocol and measures in a way that would allow to discriminate different processes engaged in the problem-solving task. Perhaps, analyzing not only the final effect but also strategies of playing might bring more interesting results. In the present study, the whole course of the game and all the keywords were registered; however, our sample turned out to be too small to reasonably assess the keywords used by the participants with regard to their usefulness and importance for the problem solution. Owing to the task specificity, it was also not possible to reliably assess how informative the chosen clips were because it seems to depend not only on the content of particular clips but also on the order of watching the clips, different for each participant, and probably on individual cognitive processing as well, since each participant might have taken into account different details from the clip and might have experienced insight at different time. Some replications would be needed to allow to apply such strategy analyses and to develop alternative indicators of ill-defined problem solving.

In our study, the task performance was related only to IQ and sex. IQ was positively related to solution quality (reasonableness and story recall) and fluency. Considering sex, women had higher scores than men in all the measures of solution creativity (fluency, flexibility, originality, and elaboration) and story recall. The relationship with IQ may be easily understood, given that intelligence is a general mental capability, involving, among other things, such abilities as reasoning, planning, abstract thinking, and problem solving (Gottfredson, 1997). The relationship between solution creativity and sex is more difficult to explain, since studies concerning sex differences in creativity mostly indicate a lack of differences between men and women; on the other hand, some other studies yield mixed results (Baer and Kaufman, 2008). However, given the scarce number of male participants in the present study, this result must be treated with caution. The issue of sex differences in ill-defined problem solving and the possible confounding effects of these differences on the role of sleep in this process requires further exploration.

To summarize, based on the results of the present study, there is no evidence for any beneficial effects of sleep on ill-defined problem solving, neither with regard to quality nor creativity of the solution. With the use of a video game concerning a complex and ambiguous crime riddle, we tried to investigate how sleep affects dealing with complex, dynamic, uncertain, and open problem situations. We also made every effort to prevent effects of experimenter expectancies by precisely presenting only previously prepared, standard instructions, as well as blind scoring of both participants' solutions and PSG recordings. Using several different measures of participants' performance, we attempted to discriminate the effects of sleep on various cognitive processes involved in ill-defined problem solving. Presumably, sleep does not benefit any of those processes. Our study adds to a growing body of evidence that sleep probably might provide an incubation gap, but not a facilitating environment for problem solving, at least with regard to ill-defined problems. Future studies are needed to further explore the potential effects of sleep on different cognitive processes required for solving various kinds of problems.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The present study was carried out in accordance with the recommendations of the Research Ethics Committee, Institute of Psychology, Jagiellonian University. All participants were given a letter of information and gave written informed consent before participation in accordance with the Declaration of Helsinki. They were financially compensated for their participation (or, in the pilot study, they got free lunch during the study and took part in a prize draw after the study). Study protocols were approved by the Research Ethics Committee, Institute of Psychology, Jagiellonian University.

AUTHOR CONTRIBUTIONS

BS, MH, MD-B, and AG conceptualized and designed the study. All authors were involved in planning. BS and MH supervised the work. AG, MD-B, DS, and MH searched the literature. MH, AG, and MD-B carried out both the pilot and the main study. MH scored PSG recordings. MH, MD-B, and DS scored participants' solutions in the pilot study. MH, MD-B, DS, and AG performed the scoring in the main study. MH and AG processed the data and performed statistical analyses. MH drafted the manuscript and designed the tables and figures. All authors discussed the results and commented on the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.00559/full#supplementary-material

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