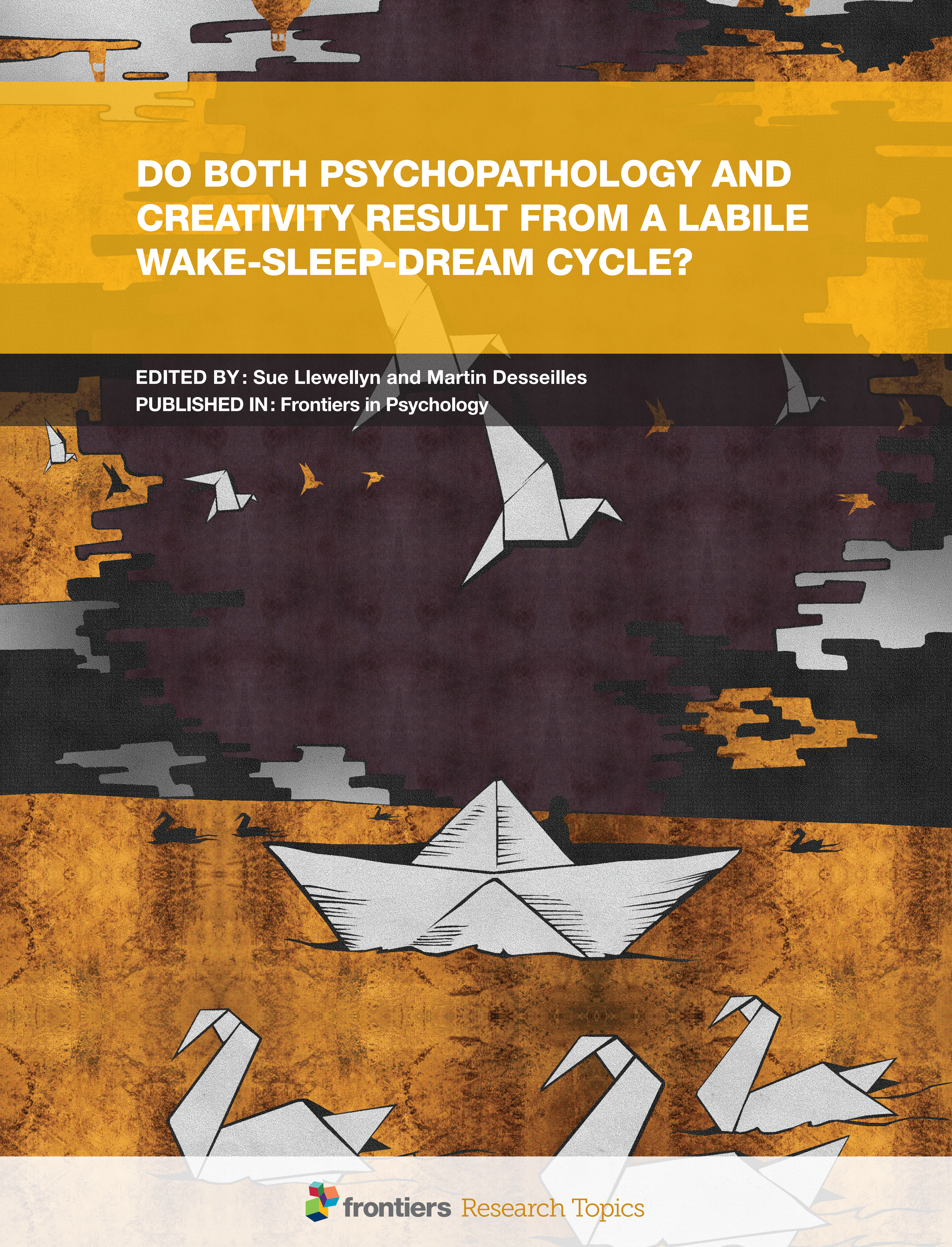

DO BOTH PSYCHOPATHOLOGY AND CREATIVITY RESULT FROM A LABILE WAKE-SLEEP-DREAM CYCLE?

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DO BOTH PSYCHOPATHOLOGY AND CREATIVITY RESULT FROM A LABILE WAKE-SLEEP-DREAM CYCLE?

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Laypeople think of wake, sleep and dreaming as distinct states of the mind/brain but “in-between”, hybrid states are recognized. For example, day-dreaming or, more scientifically, the default network occurs during wake. Equally, during sleep, lucid dreaming in rapid eye movement (REM) sleep presents as another hybrid state. But hybrid states are usually temporary. This book explores the possibility of an enduring hybrid wake-sleep-dream state, proposing that such a state may engender both creativity and psychopathologies. REM sleep is hyper-associative. Creativity depends on making remote associations. If REM sleep and dreaming begin to suffuse the wake state, enhanced creativity may result. But moderate to severe interpenetration of wake, sleep and dreaming may engender psychopathologies – as the functions of wake, sleep and dreaming are partially eroded.

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EDITORIAL
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Editorial: Do Both Psychopathology and Creativity Result from a Labile Wake-Sleep-Dream Cycle?

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Editorial on the Research Topic

Do Both Psychopathology and Creativity Result from a Labile Wake-Sleep-Dream Cycle?

We invited contributions on the following hypothesis: the boundaries between wake, sleep, and dreaming (W/S/D) can become less distinct, engendering a de-differentiated, disordered state in which wake, sleep and dreaming become interpenetrated (see Llewellyn, 2016, for a review). In other words, the state differentiation which, through differing neuromodulation and input-output gating, achieves the W/S/D cycle is disrupted. Consequently, the mind/brain assumes more of a hybrid, de-differentiated wake-sleep-dream state across the cycle. Due to the chaos dynamics of brain processes, where a small change can engender diverse results, de-differentiation can take a variety of forms. A slight to moderate degree of penetration of wake by REM sleep may result in enhanced creativity. Normal waking consciousness is a sub-critical, ordered state (Carhart-Harris et al., 2014) whereas creative states are critical. Creative insight depends on spreading neural activation to make remote associations amongst memory (including knowledge) elements (Yaniv and Meyer, 1987; Dijksterhuis and Meurs, 2006; Dijksterhuis and Nordgren, 2006; Baird et al., 2012; Ritter and Dijksterhuis, 2014). Hyperassociativity, or the ability to make remote associations, is more characteristic of rapid eye movement (REM) sleep and dreaming than either wake or non-REM sleep (Stickgold et al., 1999; Walker et al., 2002; Cai et al., 2009; Sterpenich et al., 2014). Therefore, if REM sleep begins to suffuse wake, enhanced creativity would be anticipated. But moderate to severe interpenetration of W/S/D may precipitate psychopathologies- as the distinct functions of W/S/D are partially eroded. In ADHD, for example, the W/S/D cycle is de-differentiated or labile (Kirov and Brand, 2014). If our proposal is correct an association between creativity and psychopathology would be observed. Evidence for this is accumulating, see for example, Kyaga et al. (2011), Santosa et al. (2007), and Rybakowski and Klonowska (2010).

Our contributors focus on different aspects of the complex interrelationships outlined above. First, to explicate the relationship between labile sleep and creative insight, Kirov et al. operationalized a labile sleep cycle as the rate of sleep stage transitions. They found a strong positive correlation between the rate of NREM/REM transitions and insight, after sleep, into a hidden sequence in a serial reaction time task. Second, both creative insights and psychopathologies have long thought to depend on access to, normally, unconscious associations (Ghiselin, 1952; Maher, 1972). De-differentiation of W/S/D would enable conscious access in wake to the remote associations made during REM sleep. Whereas, in a normal, differentiated sleep cycle, these associations, if retained, would remain unconscious. Yordanova et al. provide a detailed understanding of the interactions between conscious and unconscious knowledge, before, during and after sleep, which underlie insight performance on a visual serial reaction time task. Third,

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dreams have long been thought to embed personal insights. Bob and Louchakova argue for common brain processes in dreaming and dissociative states, noting that creativity during dreaming may take the form of personal insights as experiential memories which are only remotely associated become integrated in dream imagery. Continuing on the personal insight theme, Edwards et al. compare the personal insight gains when participants consider a recent dream as compared to a recent event. Using the Ullman method, self-assessment of personal insight after considering dream content was significantly higher than after considering a real life event.

Fourth, if dream and wake states become hybridized, psychopathologies may arise. Skrzypińska and Szmigielska argue those with Borderline Personality Disorder experience dream-reality confusion- defined as difficulty determining whether an event actually occurred or was an aspect of a dream. Some of those with psychopathologies are also creative, van Heugten - van der Kloet et al. explored the relationship between sleep, creativity and dissociation. They found a relationship between acute dissociative symptoms and creativity. McNamara and Bulkeley focus on the creativity of dreams and the psychopathology of religious delusions. They contend that supernatural agent cognitions link the two when REM sleep begins to pervade waking consciousness. Continuing to interrogate REM sleep, Hutchison and Rathore are interested in REM theta, noting that theta oscillations are also prominent during exploration during wake. During REM sleep, they argue that theta may drive novel associations amongst emotionally salient memory elements. Such a process may be sleep-dependent, mental exploration equating to the spreading neural activation which characterizes creative insight. Fifth and finally, two papers provide a detailed understanding of hyperassociativity during dreaming. Horton and Malinowski focus on novel associations and re-combinations of personal memory elements in dreams, arguing such re-combinations constitute creative insights which are more useful in future contexts than whole, veridical memories. Malinowski and Horton explore the links between identifying novel associations during dreams and metaphorical thinking, noting that a metaphor provides insight into how two or more entities are associated. They argue that dream metaphors derive from novel associations and can generate new, creative ideas.

Overall, the most prominent theme in our collection is that of creative or personal insight. The distinction between these two may be one of emphasis and extension. Individuals can have creative insights which extend, in the future, to socially useful innovations. But such insights depend, originally, on personally held knowledge. With an emphasis on knowledge about the person, insights can give rise to new personal knowledge which can be mobilized in a therapeutic context. Several of our papers lend support to the idea that REM sleep and dreaming engender creative insights. With a labile, de-differentiated W/S/D cycle such insights would become additionally available in wake. Our collection also extends the emergent literature on sleep, creativity and psychopathology through linking the three. However, only one paper, Bob and Louchakova, touched upon the chaos dynamics which may underlie de-differentiation. To progress work on the possible links between creativity, psychopathologies and the de-differentiation of W/S/D, interdisciplinary research on labile sleep, chaos dynamics and REM hyperassociativity is called for.

AUTHOR CONTRIBUTIONS

Both authors contributed to writing up the topic, handling the reviews and writing up the editorial.

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Labile sleep promotes awareness of abstract knowledge in a serial reaction time task

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Sleep has been identified as a critical brain state enhancing the probability of gaining insight into covert task regularities. Both non-rapid eye movement (NREM) and rapid eye movement (REM) sleep have been implicated with offline re-activation and reorganization of memories supporting explicit knowledge generation. According to two-stage models of sleep function, offline processing of information during sleep is sequential requiring multiple cycles of NREM and REM sleep stages. However, the role of overnight dynamic sleep macrostructure for insightfulness has not been studied so far. In the present study, we test the hypothesis that the frequency of interactions between NREM and REM sleep stages might be critical for awareness after sleep. For that aim, the rate of sleep stage transitions was evaluated in 53 participants who learned implicitly a serial reaction time task (SRTT) in which a determined sequence was inserted. The amount of explicit knowledge about the sequence was established by verbal recall after a night of sleep following SRTT learning. Polysomnography was recorded in this night and in a control night before and was analyzed to compare the rate of sleep-stage transitions between participants who did or did not gain awareness of task regularity after sleep. Indeed, individual ability of explicit knowledge generation was strongly associated with increased rate of transitions between NREM and REM sleep stages and between light sleep stages and slow wave sleep. However, the rate of NREM–REM transitions specifically predicted the amount of explicit knowledge after sleep in a trait-dependent way. These results demonstrate that enhanced lability of sleep goes along with individual ability of knowledge awareness. Observations suggest that facilitated dynamic interactions between sleep stages, particularly between NREM and REM sleep stages play a role for offline processing which promotes rule extraction and awareness.

Keywords: labile sleep, sleep stage transitions, NREM–REM–NREM transitions, explicit knowledge, insight, serial reaction time task

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Introduction

Sleep has been identified as a critical brain state involved in consolidation of both explicit and implicit memories (Maquet, 2001; Smith, 2001; Born et al., 2006; Walker and Stickgold, 2006; Diekelmann and Born, 2010), where consolidation refers to a post-learning process that stabilizes and strengthens the new memory traces established at learning (Lechner et al., 1999; Rasch and Born, 2013). Recent studies have shown that sleep may not only stabilize but also reorganize memory representations such that performance after sleep can qualitatively differ from what has been originally encoded (Fenn et al., 2003; Wagner et al., 2004; Ellenbogen et al., 2007). This reorganization has been first prompted in the study of Wagner et al. (2004) where a hidden regularity was implemented in a task to be learned (the number reduction task, NRT). Acquiring explicit knowledge of this hidden regularity (i.e., gaining insight into it) allowed participants to find an alternative direct solution of the task. Wagner et al. (2004) found that sleep enhanced the probability of gaining insight into the covert task structure, as evidenced by a substantially higher number of participants who discovered the hidden regularity (solvers) when the test was performed after sleep compared with wakefulness. Using the same task, Darsaud et al. (2011) have revealed that after sleep, only in participants who gained awareness of the hidden rule, were neural response patterns transformed overnight. Specifically, overnight modulation was observed in the ventral medial prefrontal cortex, a region implicated in the consolidation of memory and uniquely activated before gaining insight at post-sleep retest. Notably, however, already at implicit training before sleep, the neural responses of solvers and non-solvers differed because areas mediating controlled processes (frontal and parietal cortices and the insula) were more active in future solvers, in contrast to significant hippocampal activation in non-solvers (Darsaud et al., 2011). Thus, offline reorganization of encoded memories during sleep is related to subsequent explication of abstract knowledge. Yet, cognitive strategies during encoding may critically determine the offline consolidation supporting subsequent insight.

According to Lewis and Durrant (2011) sleep, in particular the slow-wave sleep (SWS) fraction of non-rapid eye movement (NREM) sleep supports abstraction by re-activating in an overlapping manner memories that are common to several representations. This may lead to strengthening of common elements. In contrast to idiosyncratic elements, these common elements undergo a preferential cortical consolidation either actively (Diekelmann and Born, 2010; Rasch and Born, 2013) or passively (Tononi and Cirelli, 2003, 2006, 2014; Lewis and Durrant, 2011), thus potentiating the offline formation of a new neural representation. Shared features thus undergo selective strengthening and subserve integration, abstraction of rules, insight into hidden solutions, and false memory formation (Lewis and Durrant, 2011). This model is substantiated by findings from both animal and human studies demonstrating that neural patterns of specific behaviors during wake are reactivated during SWS (Wilson and McNaughton, 1994; Lee and Wilson, 2002; Huber et al., 2004, 2006; Rasch et al., 2007; O'Neill et al., 2010).

Previous studies using tasks with hidden regularities have provided evidence for the role of SWS for explicit knowledge generation after sleep. Employing a split-night design, where the role of early night sleep, rich in SWS, and late-night sleep, rich in rapid eye movement (REM) sleep, could be explored separately, Yordanova et al. (2008) have demonstrated that SWS, but not REM sleep, plays a role for the transformation of implicit knowledge generated before sleep to explicit (conscious) knowledge after sleep. The major observation was that the rate of subjects who gained insight into NRT after sleep on the basis of pre-sleep implicit knowledge was significantly higher across early- than late-night sleep. In contrast, late-night subjects preferentially preserved rather than transformed implicit knowledge acquired before sleep (Yordanova et al., 2008). Also, SWS alters the processing of items predicted by the hidden NRT regularity by inducing changes of both information-based processes and functional brain states toward insightful solutions (Yordanova et al., 2009a, 2010). Within the information- and process-based distinction of consolidation, it has been further demonstrated that SWS promotes insight after sleep by consolidating mainly the information that had been encoded and learned explicitly before sleep (Yordanova et al., 2009b), with slow sleep spindles during SWS supporting implicit-to-explicit knowledge transformation (Yordanova et al., 2012). Similarly, a more recent nap study provided further evidence for the enhancing role of SWS for insight solutions (Beijamini et al., 2014).

While these reports emphasize the key role of SWS for explicit knowledge generation, REM sleep also has been implicated with mediating knowledge awareness (Edwards et al., 2013). Walker et al. (2002b) have found that awakenings during REM sleep produce a significant increase in the rate of associative anagram solving relative to awakenings during NREM sleep, suggesting that the neurophysiology of REM sleep maintains cognitive processing that is more flexible than that of NREM sleep. Likewise, REM sleep enhances more the integration of unassociated information for creative problem solving as compared to NREM sleep (Cai et al., 2009). Stickgold et al. (1999) also have pointed to the specific role of REM sleep in associative memory systems, which may be critical for the formation of new abstract representations (Walker and Stickgold, 2010; Stickgold and Walker, 2013). In support, Peigneux et al. (2003) have reported that brain regions involved during learning a serial reaction time task (SRTT), where a hidden regularity was probabilistic, were re-activated during subsequent REM sleep.

Together, these previous studies reveal a role for both SWS and REM sleep in bringing implicitly learned information to awareness. According to the sequential hypothesis (Giuditta et al., 1995), memories acquired during wakefulness are processed during sleep in two serial steps occurring during SWS and REM sleep. Specifically, it is suggested that during SWS, memories are distinguished from irrelevant or competing traces that undergo downgrading or elimination; during REM sleep, retained processed memories are stored again and integrated with preexisting memories (Giuditta, 2014). With regard to "recovery sleep function," Vyazovskiy and Delogu (2014) also propose that NREM and REM sleep have distinct and complementary contributions to the overall function of sleep. They suggest that functionally interconnected neuronal networks during NREM sleep enable information processing, synaptic plasticity, and prophylactic cellular maintenance ("recovery process"). In turn, periodic excursions into an activated brain state – REM sleep – perform "selection" of recovered brain networks. Targeting specifically the offline functions of sleep to unitize, assimilate, and abstract memory representations, Walker and Stickgold (2010) and Stickgold and Walker (2013) propose that the NREM sleep represents an initial stage of offline processing, during which new episodic memories are preferentially consolidated by keeping their characteristics separate and distinct. By contrast, at a second, REM-dependent stage, these newly encoded and NREM sleep-consolidated memories are integrated into associative networks supporting integration with old memory schemes, rule extraction, and generalization. Critically, with regard to natural sleep architecture, effective integration of these memories is suggested to take several NREM–REM cycles or even multiple nights before optimal representations are complete (Walker and Stickgold, 2010). In the same line, Llewellyn and Hobson (2015) posit a key role for REM after NREM sleep to incorporate emotional information into nodes of mentally translated new episodic memories.

Regarding the dynamic roles of NREM and REM sleep for explicit knowledge generation within a two stage model of sleep function (Walker and Stickgold, 2010), we propose that the interactions between sleep stages might be critical for integrating memories which support awareness after sleep. In the present study, we test the hypothesis that the increased frequency of transitions between sleep stages, in particular between NREM and REM sleep stages, is associated with the ability of explicit knowledge generation after sleep.

Materials and Methods

Participants

Fifty-three students at the University of Lübeck (28 female) participated in the study as part of a larger experiment designed to investigate effects of sleep on hemisphere-specific processing. Participants were between 20 and 30 years of age (mean 23.4 ± 2.16 years), had normal or corrected to normal vision as well as normal color vision, were right-handed (evaluated according to the Edinburgh Handedness Inventory, Oldfield, 1971) and did not have histories of neurologic, psychiatric, sleep disturbances, or irregular sleep-wake schedules. Before and during the experiment, no drugs, alcohol, or caffeine drinks were used by the subjects. The experiment was conducted in the sleep electroencephalography (EEG) laboratory at the Department of Neurology at the University of Lübeck. The study was performed according to the clinical standards of the Declaration of Helsinki and was approved by the university's Ethic Committee. All participants received monetary compensation (60 €) for their participation and gave informed written consent before the study.

Experiment

Participants performed a version of the serial response time task (Nissen and Bullemer, 1987) where stimuli were presented in the left or right visual half-field (varying across participants, see Verleger et al., 2015, for details) with a first, practice session in the evening and a second, test session in the morning after sleep.

Stimuli and Task

The task was a four-choice visual motor task, in which motor responses with four fingers of one hand had to be selected to four colored circles. Colored circles were blue, red, yellow, or green. Their center was located 4.5° laterally from the center of the white screen at horizontal midline. A dark-gray circle of same size was presented at the other side of the screen symmetrically to the color circle. Index to little fingers of the responding hand rested at the four active keys of a custom-made keyboard which contained sets of four keys for either hand. In each trial, a colored circle (blue or red or yellow or green) was presented on one side of the screen, always left of fixation for half of participants ($n = 28$) and always right for the other half ($n = 25$). Responses to the circles had to be made with the ipsilateral hand, by pressing the index, middle, ring, or little finger correspondingly to blue, red, yellow, or green circles, respectively. The stimulus was presented for 200 ms, and the next color circle appeared 800 ms after the correct response.

Task structure shown in **Figure 1A** followed the design used by Cohen et al. (2005). From participants' point of view, the task during learning consisted of three episodes with self-terminated breaks between episodes, where one of the four colors appeared in each trial and had to be responded by pressing the appropriate key. The number of trials in each episode was 280, 400, and 280, altogether 960. Untold to participants, each of the three episodes was a "sandwich" where the outer trials (first 50 and last 50) were random, whereas the inner trials repeated a fixed sequence of 12 stimuli (15, 25, and 15 times in the three episodes). The fixed sequence (**Figure 1B**) was B R Y B G Y R B Y G R G (meaning Blue, Red, Yellow, and Green). During test, the same "sandwich" structure was used, with the outer 50 trials being random and the inner 180 trials following the fixed sequence of 12 elements. Similar to learning, participants were not informed about the occurrence of regular sequences during test. After the testing session, subjects filled in a questionnaire to probe their explicit knowledge related to the hidden task structure as well as possible strategies used during task performance.

Procedure

Participants spent an adaptation (non-learning) night in the laboratory with a polysomnographic (PSG) recording, followed after 2–10 days (~7 days) by the experimental night which was preceded by the learning session and followed by the test session (**Figure 1C**). For all participants, the non-learning night was before the learning night. For the learning night, participants reported to the laboratory at ~20:00 h. After placement of electrodes for EEG/PSG recording, they performed the task (three blocks of practice) and thereafter went to bed at ~22:30 h. After 8 h of sleep, participants were awakened at ~07:00 h. They were only awakened from light sleep stages 1 or 2 to avoid cognitive disturbances that can occur after awakenings from SWS or REM sleep. Finally, participants performed the test session (one block) starting at ~07:30 h (**Figure 1C**). Subjective levels of sleepiness, activation, boredom, concentration, and motivation were assessed on five-point scales immediately before and after each session of practice (learning) and retest.

Sleep EEG Recording and PSG Analysis

During the two nights (non-learning and learning), EEG was recorded with Ag–AgCl electrodes (Easycap, http://

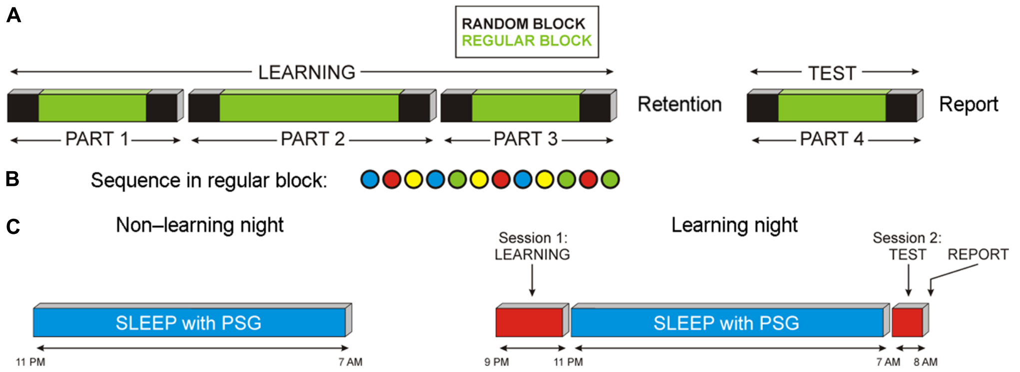

FIGURE 1 | Schematic presentation of the experimental design. (A) SRTT was performed in four parts. Unknown to participants, each part was divided in three blocks. Blocks indicated in black contained random sequences of stimuli (random block); blocks indicated in green contained regularly ordered stimuli (regular blocks). Participants practiced SRTT in evening sessions (LEARNING), and performed a TEST session after retention period. **(B)** Illustration of the fixed sequence of stimuli in regular blocks. **(C)** Timing of the experiment in the non-learning and learning nights.

www.easycap.de) from 26 scalp electrodes according to the International 10/20 system: F7, F3, Fz, F4, F8, FC3, FCz, FC4, T7, C3, Cz, C4, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, PO7, PO8, O1, O2 (BrainAmp MR plus, Gilching, Germany, cut-off frequencies DC and 250 Hz, sampling rate 500/s). Additional electrodes were placed at the nose-tip for reference and at Fpz as a ground. Also, electromyogram (EMG) using submentally attached electrodes, and vertical (from electrodes placed above and below the right eye) and horizontal (from electrodes placed on both outer canthi of the orbits) electrooculogram (EOG) were recorded. Analyzes were performed by means of Brain Vision Analyzer 2.1 (Gilching, Germany) and specially designed software on Matlab R2013b (The MathWorks Inc.).

Off-line PSG analysis including EEG (C3 and C4), EMG, and EOG was performed. PSG data were analyzed visually in 30-s epochs according to standard criteria (Rechtschaffen and Kales, 1968) by two experienced raters blind to participants' age, gender, and behavioral performance. The distribution of the different sleep stages in the non-learning and learning nights showed normal sleep architecture.

In addition, the number of sleep stage transitions (SST) was measured. This included (1) transitions to wake after sleep onset from Stages 2 (S2) and SWS of NREM sleep, and from REM sleep, and from wake to these sleep stages; (2) transitions from NREM to REM sleep, as well as from REM to NREM sleep (NR–RN); (3) all transitions between Stage 1 (S1), S2, and SWS. The numbers of each type of SSTs were normalized separately by calculating SST per hour of total sleep time.

Explicit Knowledge Groups

Following the experimental protocol of Nissen and Bullemer (1987), at the end of the test session, participants were asked to report verbally if they had detected any regularity in the appearance of stimuli and, if so, to write on paper any regular sequence they had noted. To quantify the gain of explicit sequence-specific knowledge (ExK) in the SRTT, participants were scored from 1 to 5. In case of no sequence being detected, the participant was scored with 1. Based on their written reproduction, participants were scored with 2 if they could recover a single correct sequence of 3–4 items, with 3 if they reproduced two correct sequences of 3–4 items each, with 4 if they could reproduce a correct sequence of more than 8 items of the 12-item order, and with 5 if they were able to report the whole sequence of 12 items. For example, a participant was scored with 2 if he/she was able to reproduce correctly YBGY or GYR (a correct 3- to 4-item fragment of the 12-item sequence). An example of reporting 2 correct separate fragments is YBG and RBYG (scored 3), in contrast to, e.g., a correct BRYBGYRBY reproduction scored 4. Participants scored with 1 ($n = 30$) and 2 ($n = 11$) were assigned to the group of no gain of ExK about sequence (No-ExK, non-solvers, $n = 41$), those scored with 3 ($n = 6$), 4 ($n = 4$), and 5 ($n = 2$) were assigned to the group of gain of ExK about sequence after sleep (ExK, solvers, $n = 12$).

Statistical Analysis

All PSG parameters including the normalized SST were analyzed using a mixed analysis of variance (ANOVA) design with the between-subjects variable Group (no-ExK vs. ExK, i.e., non-solvers vs. solvers) and the within-subjects variable night (non-learning vs. learning). In addition, Pearson's two-tailed correlations and a multiple regression analysis (step-wise model) were conducted as detailed in the Section "Results".

Results

Group mean values of the analyzed PSG parameters are presented in **Table 1** and statistical results from ANOVAs are presented in **Table 2**. The tables demonstrate that none of the major PSG parameters (total time in bed, total sleep time, sleep onset latency, sleep efficiency, latencies to SWS and REM sleep, and duration of all sleep stages) differed between the groups of solvers and non-solvers [Group, $F(1/51) < 2.2$, $p > 0.15$], nor were between-group differences in these PSG parameters modulated significantly by Night [Group × Night, $F(1/51) < 3.9$, $p > 0.05$]. While total time in bed and total sleep time did not

TABLE 1 | Sleep PSG parameters for the non-learning and learning night.

	No explicit knowledge ($n = 41$)		**Explicit knowledge ($n = 12$)**	
	Non-learning night	**Learning night**	**Non-learning night**	**Learning night**
Duration measures (min)				
Total time in bed (TIB)	495 ± 69	477 ± 53	481 ± 51	461 ± 48
Total sleep time (TST)	469 ± 39	464 ± 45	452 ± 36	448 ± 46
Sleep onset latency	25 ± 10	13 ± 10	29 ± 13	13 ± 6
SE (TST/TIB) %	95 ± 2	97 ± 2	94 ± 3	97 ± 2
Latency to SWS	25 ± 15	13 ± 4	34 ± 29	15 ± 6
Latency to REM sleep	85 ± 36	60 ± 19	83 ± 33	56 ± 16
Duration of sleep stages (% of TST)				
Wake	4.6 ± 3.9	2.2 ± 4.6	4.8 ± 4.2	0.8 ± 1.2
Stage 1	4.5 ± 2.1	1.9 ± 1.8	5.4 ± 2.1	1.2 ± 0.6
Stage 2	49.1 ± 6.4	44.5 ± 6.5	47.8 ± 6.4	44.8 ± 6.8
SWS (Stages 3 + 4)	14.9 ± 3.6	20.3 ± 5.2	15.1 ± 4.1	21.5 ± 4.5
REM sleep	24.9 ± 4.7	29.7 ± 6.1	25.3 ± 5.1	30.5 ± 4.7
Movement time	1.9 ± 1.2	1.9 ± 1.8	1.8 ± 0.9	1.3 ± 0.9
Rate of SST (Number of transitions per hour)				
Total SST	4.5 ± 0.9	4.1 ± 0.8	6.0 ± 1.1	5.9 ± 1.1
SST to Wake	1.2 ± 0.5	0.5 ± 0.4	1.0 ± 0.5	0.4 ± 0.4
SST NR–RN	1.4 ± 0.4	1.5 ± 0.3	2.1 ± 0.4	2.1 ± 0.3
SST: S1, S2, and SWS	1.3 ± 1.1	2.0 ± 0.9	2.6 ± 1.0	3.3 ± 1.0

Shown are group mean values ± SD. SE, sleep efficiency; SWS, slow wave sleep; REM, rapid eye movement; SST, sleep stage transitions; NR, non-REM (NREM) to REM (transitions); RN, REM to NREM (transitions); SST: S1, S2 and SWS, transitions between Stage 1, Stage 2 of NREM sleep and SWS.

TABLE 2 | ANOVA results.

	Main effects				**Interaction**	
	Group		**Night**		**Group × Night**	
	F	***P***	***F***	***p***	***F***	***p***
TIB	2.1	0.2	2.7	0.1	0.2	0.9
TST	2.2	0.1	0.4	0.5	0.1	0.9
SOL	0.3	0.7	63.6	<0.001	1.3	0.3
SE (TST/TIB) %	0.3	0.6	56.3	<0.001	0.9	0.3
Latencies to sleep stages						
SWS	3.1	0.1	24.9	<0.001	1.1	0.3
REM sleep	0.2	0.7	18.2	<0.001	0.3	0.7
Duration of sleep stages (% of TST)						
Wake	0.0	0.9	14.8	<0.001	0.1	0.4
Stage 1	1.4	0.3	76.2	<0.001	4.0	0.1
Stage 2	0.1	0.8	11.5	0.001	0.6	0.5
SWS (Stages 3+4)	0.4	0.5	42.4	<0.001	0.3	0.6
REM sleep	0.2	0.7	32.2	<0.001	0.2	0.7
Movement time	0.6	0.4	4.7	0.04	0.2	0.9
Rate of SST						
Total SST	**37.2**	**<0.001**	10.2	0.002	**4.0**	**0.05**
SST to Wake	1.7	0.2	74.3	<0.001	0.2	0.7
SST NR–RN	**37.2**	**<0.001**	5.2	0.03	1.2	0.3
SST: S1, S2, and SWS	**18.5**	**<0.001**	19.4	<0.001	0.0	0.9

Group: no explicit knowledge (n = 41) vs. explicit knowledge (n = 12); Night: non-learning night vs. learning night. F, Fisher coefficient; p, level of significance. Degrees of freedom are 1.51 for all effects. Significant effects including group are in bold. TIB, total time in bed; TST, total sleep time; SOL, sleep onset latency; SE, sleep efficiency; SWS, slow wave sleep; REM, rapid eye movements; SST, sleep stage transitions; NR, non-REM (NREM) to REM sleep (transitions); RN, REM to NREM sleep (transitions); SST: S1, S2 and SWS, transitions between Stage 1, Stage 2 of NREM sleep and SWS.

differ between the learning and non-learning nights, sleep onset latency, latencies to SWS and REM sleep and the amount of wake, Stage 1, Stage 2 of NREM sleep and of movement time decreased significantly in the learning relative to the non-learning night, showing the effect of becoming adapted to the lab environment. Correspondingly, sleep efficiency and the amounts of SWS and REM sleep significantly increased ($p < 0.001$; **Table 2**).

Figure 2 illustrates hypnograms of two representative participants with and without explicit knowledge after sleep. The total rate of transitions was larger in solvers than non-solvers (Group, $p < 0.001$) and was reduced during post-learning sleep (Night, $p = 0.002$), but this decrease was less expressed in solvers than in non-solvers (Group × Night, $p = 0.05$; **Table 1**). These effects were not due to transitions from sleep stages to wake after sleep onset which did not differ between solvers and non-solvers (Group, $p = 0.2$). Although the rate of transitions to wake was significantly reduced in the learning relative to the first non-learning night (Night, $p < 0.001$), this effect was not modulated by the ability of explicit knowledge generation after sleep (Group × Night, $p = 0.7$).

Rather, as **Tables 1** and **2** and **Figure 3** show, these effects on total rate of transmission were due to transitions between sleep stages. First, the rate of NR–RN transitions was significantly larger in solvers than non-solvers (Group, $p < 0.001$), with this difference being independent from the post-learning enhancement of NR–RN transitions (Night, $p = 0.03$; Group × Night, $p = 0.3$). Second, transitions between sleep stages other than NR–RN (Stage 1 and Stage 2 of NREM sleep and SWS) was significantly higher in solvers than non-solvers in the two nights (Group, $p < 0.001$; Group × Night, $p = 0.9$). Pre-sleep learning was associated with a higher rate of SST between light sleep stages (Stage 1 and Stage 2 of NREM sleep) and SWS (Night, $p < 0.001$).

These ANOVA results were mirrored in results of correlating the ExK scoring from 1 to 5 with each of these parameters for either night separately (non-learning and learning): total rate of transitions ($r = 0.78$ and 0.81, $p < 0.001$); rate of transitions NR–RN ($r = 0.84$ and 0.75, $p < 0.001$); rate of transitions between other sleep stages ($r = 0.44$ and 0.66, $p < 0.001$). The correction for multiple tests (two nights × three parameters) yielded $p = 0.006$, validating the significance of the so obtained correlations. In a multiple regression stepwise analysis, these transition parameters, age (in months) and gender were included as predictors of ExK scores (1–5). **Figure 3** displays these correlations for the NR–RN transitions. A significant model solution [$r = 0.837$, $r^2 = 0.701$; $F(1/51) = 119.4$, $p < 0.001$] extracted only the rate of NR–RN as a predictor of the amount of explicit knowledge generation after sleep ($B = 2.1$, $\beta = 0.837$, $t = 10.9$, $p < 0.001$), with none of the other variables being selected as a predictor.

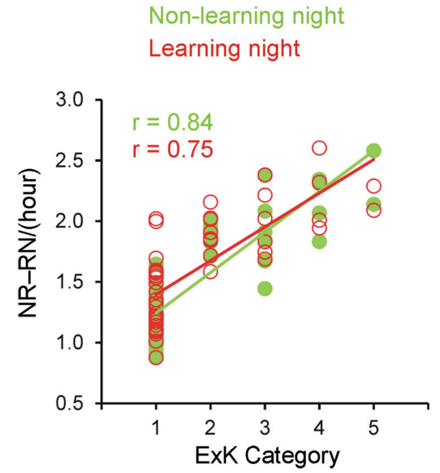

FIGURE 3 | Correlations between the explicit knowledge category and transitions from non-rapid eye movement (NREM) sleep to REM sleep and from REM to NREM sleep on both the non-learning and learning nights. ExK, explicit knowledge; NR, rate of transitions from NREM to REM sleep per hour of total sleep time; RN, rate of transitions from REM to NREM sleep per hour of total sleep time.

Discussion

Based on models about the integrative function of sleep stages for offline information processing (e.g., Giuditta et al., 1995; Walker

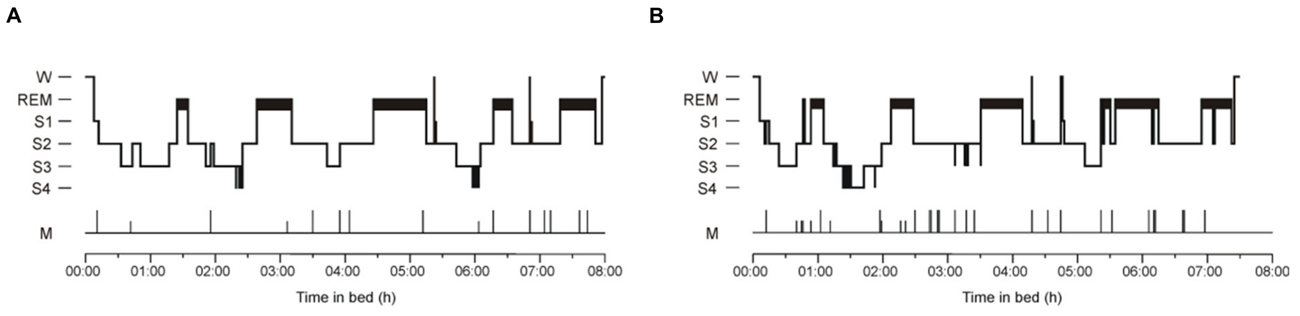

FIGURE 2 | Representative hypnograms of (A) a participant who did not gain explicit knowledge and (B) a participant who gained explicit knowledge. W, Wake; S1, Stage 1; REM, rapid eye movement sleep; S2, Stage 2 non-REM sleep; S3, Stage 3 of slow wave sleep (SWS); S4, Stage 4 of SWS; M, epochs containing movements.

and Stickgold, 2010; Stickgold and Walker, 2013; Giuditta, 2014; Llewellyn and Hobson, 2015), the present study explored the association between the frequency of transitions between sleep stages and ability to generate explicit knowledge after sleep. The SRTT was used (in a lateralized version) to induce implicit encoding of a hidden sequence before sleep. The amount of explicit knowledge about sequence-specific information was estimated after sleep and correlated with the rate of SST during a full-night sleep.

According to the major results, gain of explicit knowledge about task regularity following incidental pre-sleep learning of SRTT was strongly associated with increased rate of transitions between NREM and REM stages of sleep. Additionally, this explicit knowledge was related to an overall increase in SST, including also those between sleep Stage 1, Stage 2 of NREM sleep, and SWS. However, the increased rate of NR–RN transitions specifically predicted the amount of explicit knowledge after sleep as indexed by the multiple regression model. Together, these results reveal that in individuals capable of explicating abstract information, there is enhanced lability of sleep stages marked by facilitated dynamic transitions between them, particularly between NREM and REM sleep stages.

Sleep stage shifts have been identified as a reliable marker of sleep continuity, in addition to standard measures (e.g., arousal index; Stepanski et al., 1984; Haba-Rubio et al., 2004). In a study of more than 5600 participants, only transitions from sleep stages to awakenings after sleep onset have been demonstrated to affect daily functioning, thus being recognized as markers of fragmented sleep or markers of impaired sleep micro-architecture (Laffan et al., 2010). In contrast, unstable and transitory sleep stages do not index impairment of sleep architecture and are not accompanied by a less restorative function of sleep (Swarnkar et al., 2009; Laffan et al., 2010). Specifically, transitions between NREM and REM sleep stages had no significant effect on self-reported sleep quality and daytime neurobehavioral functions (Laffan et al., 2010). The results of the present study demonstrate that the rate of transitions from sleep stages to wake did not differ between participants generating and not generating explicit knowledge after sleep. If anything, trends toward reduced rate of transitions to wake and a decreased amount of wakes after sleep on set also were observed in participants with explicit knowledge, in addition to preserved indices of sleep efficiency (**Table 1**). Therefore, the increased rate of SST observed here does not reflect fragmented sleep macro-architecture in explicit solvers. Rather, it reveals a specific quality of sleep architecture in relation to the capacity to generate explicit abstract knowledge about implicitly learned hidden regularity.

The observation that the transitions between all sleep stages were significantly more frequent in subsequent ExK solvers indicates that the pronounced facilitation of shifts between REM and NREM episodes is rather an expression of a more fundamental feature of sleep architecture characterized by general lability. This notion is supported by the result that solvers manifested increased rate of transitions in both the non-learning and learning nights. Hence, facilitated inter-stage dynamics during sleep appears as an individual trait characteristic potentiating a predisposition to explicit abstraction. The novel finding here is that such individual traits are marked by features of sleep continuity.

These observations are consistent and extend reports according to which individual ability for post-sleep explicit extraction of regularity may be associated with an increase in other neurophysiologic signature of sleep, namely slow spindles (8–12 Hz) during SWS (Yordanova et al., 2012). In that previous study that used the NRT, data from control nights were not available for analysis, so we could not decide whether this feature was specific to the night after the first task session or reflected some general trait of task solvers. Analyses of sleep spindles from the present SRTT suggest that both alternatives apply (Yordanova et al., submitted). The present observations are also broadly in line with previously established correlations between individual intellectual capacity and Stage 2 of NREM sleep-specific EEG (sleep spindles) signatures (Bódizs et al., 2005; Schabus et al., 2006; Fogel and Smith, 2011). Confirming previous studies with NRT (Wagner et al., 2004; Yordanova et al., 2008, for the relevant early-night group), standard evaluation of PSG parameters including the amount of sleep stages did not capture individual differences between subjects who had the ability to bring knowledge to awareness and those who did not. Thus, labile sleep and facilitated transitions between distinct sleep stages are originally revealed here as a marker for individual capacity of extracting abstract information.

On the other hand, the observation that sleep-stage transitions (excluding those to and from wake) increase in the learning relative to the non-learning night in all participants, independently of the ability to generate explicit knowledge after sleep, indicates that sleep continuity and macro-architecture are sensitive to pre-sleep learning. The experimental setup of the present study [e.g., combined application of regular and random blocks (Cohen et al., 2005), a lateralized version of the classical SRTT (Schmitz et al., 2013; cf. Verleger et al., 2015, for details)], duration of implicit learning sessions of about (30 min, etc.) may have affected specific sleep characteristics (Al-Sharman and Siengsukon, 2014). For instance, a specific increase in both SWS and REM sleep in response to other types of preceding implicit visuomotor learning is well documented (e.g., Maquet, 2001; Tononi and Cirelli, 2014). Our current observations of shortened latencies to SWS and REM sleep and increase in their amounts on the second relative to the first night are in line with the above mentioned effects of pre-sleep learning. Yet, these effects were accompanied by shortened sleep onset latency, improved sleep efficiency and reduced amounts of wake and movement time after sleep onset, consistent with expected influences of adaptation night on sleep (Agnew et al., 1966). Particularly with regard to SST, the decreased rate of total SST and rate of SST to wake also may reflect differences not related to pre-sleep learning in the second night but to the impact of adaptation during the first non-learning night (Agnew et al., 1966). It is a limitation of the present study that the non-learning night served as adaptation night, and that the non-learning and learning nights were not counterbalanced across subjects, nor was an additional purely adaptation night used for control. However, the observed differences in sleep between the two nights may not be readily attributed to adaptation, since in our study, the two nights of sleep (without and with learning) were not consecutive, but were divided by an interval of about 7 days. More important in the context of SST was the observation that the rate of transitions between sleep stages (NR–RN and other, **Tables 1** and **2**) increased after learning, which may not be predicted by effects of adaptation.

The new evidence provided by the current study is that pre-sleep sensorimotor learning of structured information is specifically associated with increased probability of transitions between sleep stages. There are experimental grounds to interpret this result as reflecting the consolidation functions of sleep since post-sleep improvement of both procedural and declarative memories have been linked with Stage 1 (van Dongen et al., 2011), Stage 2 (Walker et al., 2002a; van Dongen et al., 2011; Llewellyn and Hobson, 2015) and SWS stages of NREM sleep (revs. Diekelmann and Born, 2010; Rasch and Born, 2013; Stickgold and Walker, 2013). There can be, however, also a non-consolidation explanation for the increased rates of transitions after learning. Previously, dynamic features of brain electrophysiological states have been exclusively characterized with respect to spatio-temporally identified functional microstates (Lehmann et al., 2009; Lehmann and Michel, 2011). Functional microstates have been shown to operate on different time scales (from hundreds of milliseconds to 16 s, Van De Ville et al., 2010) and to be present in sleep stages (Wehrle et al., 2007; Brodbeck et al., 2012). Functionally, EEG microstates are understood to represent spontaneous fluctuations of activity in large scale brain networks (Koenig et al., 2002; Michel et al., 2009; Britz et al., 2010). They have been discussed as correlates of information processing steps, in the sense of "atoms of thought" (Lehmann and Michel, 2011) tentatively inducing specific spontaneous mentations (Lehmann et al., 1998). The dynamics of this spatio-temporal micro-architecture also has been suggested to drive transitions to sleep stages (Brodbeck et al., 2012). Although in the present study, state dynamics was examined for classical sleep stages, facilitated transitions after pre-sleep learning as a state-dependent feature, and in subjects with high capacity for explicit knowledge abstraction as a trait-dependent feature, may be a reflection of a more global regulation of dynamic brain states associated with neural network functioning.

Notably, the present results extract a specific role of transitions between NREM and REM sleep stages for explicit knowledge generation after sleep. This role is emphasized not only by significant differences between subsequent explicit knowledge vs. no-knowledge, but mainly by the predictive effect of RN–NR transitions on gradual amounts of explicit knowledge recovery. These observations generally substantiate models of sleep function according to which offline processing of memory representations requires the sequential or integrative contributions of both NREM and REM sleep stages (Giuditta et al., 1995; Giuditta, 2014), especially with regard to rule extraction and generalization (Walker and Stickgold, 2010; Stickgold and Walker, 2013). Specifically, pre-sleep learning was found here to increase NR–RN transitions in both solvers and non-solvers pointing to the potentiating effect of pre-sleep encoding and/or activation on the frequency of subsequent NREM–REM interactions. On the other hand, causality between increased rate of RN–NR transitions and explicit knowledge after sleep may not be inferred since higher frequency of NR–RN transitions did not generate explicit rule extraction in non-solvers. Hence, increased rate of NR–RN shifts both after learning and in relation to individual ability for knowledge explication can be accounted for by the assumption that multiple NREM–REM cycles are required to achieve optimal representations for rule extraction (Walker and Stickgold, 2010). Within this notion, the present results suggest that a critical threshold of transitions rate is needed to reach effective integration of representations, which can only be achieved by individuals manifesting a high background rate of transitions (solvers). The methodology of the present study does not allow specifying exactly which mechanisms are involved in NREM–REM sleep interactions so that knowledge consolidation and abstraction can be enhanced. It can be, however, concluded that such mechanisms of inter-stage interactions are sensitive to information encoded before sleep, in addition to their neuroplasticity modulations.

Theoretical implications of these interactions refer essentially to consecutive iterations of memory consolidation processes supported by multiple transitions between NREM and REM sleep stages (Rasch and Born, 2013; Stickgold and Walker, 2013; Llewellyn and Hobson, 2015), or between other sleep stages, Stage 1 and Stage 2 of NREM sleep (Walker et al., 2002a; van Dongen et al., 2011). Other intriguing perspectives relevant for future studies also exist. One such perspective is raised by the beneficial role of dreaming and dream contents for insightful behaviors (Edwards et al., 2013). Wamsley et al. (2010) have demonstrated that improved task performance at retest after NREM sleep was strongly associated with task-related dream imagery, suggesting that dream experiences reflect the process of offline reactivation of recently formed task memories. Also, wakefulness and dream mentations appear to rely on identical neurophysiologic substrates at macro- and meso-level of organization (Marzano et al., 2011; De Gennaro et al., 2012; Scarpelli et al., 2015). It is plausible that by virtue of the ideomotor potential of mental images (Hommel et al., 2001; Hommel, 2009) enhanced dream recall during wake triggers (or potentiates) the activation of the task-related neural substrate which has been reorganized during sleep (Wamsley et al., 2010), thus promoting access to awareness of previously un-explicated information. As an additional experimental direction, investigations of offline emotional processing can be considered. In fact, an enhancing function of dream content for insight may be grossly substantiated by powerful emotional activations integrated in the consolidated memory items during REM sleep (Nishida et al., 2009; Goldstein and Walker, 2014), thus rendering them more distinct (Llewellyn, 2013; Llewellyn and Hobson, 2015). Multiple iterations of these processes may optimize the node structure of integrative gist, promoting knowledge extraction and awareness.

Author Contributions

Substantial contributions to the conception and design of the work: RK, RV, JY; Acquisition, analysis of data: RK, VK, RV, JY; Interpretation of data: RK, VK, RV, JY; Drafting the work and revising it critically for important intellectual content: RK, VK, RV, JY; Drafting the work and revising it critically for important intellectual content: RK, VK, RV, JY; Final approval of the version to be published: RK, VK, RV, JY. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: RK, VK, RV, JY.

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Increased Performance Variability as a Marker of Implicit/Explicit Interactions in Knowledge Awareness

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Only some, but not all, individuals who practice tasks with dual structure, overt and covert, are able to comprehend consciously a hidden regularity. The formation of implicit representations of regularity has been proposed to be critical for subsequent awareness. However, explicit knowledge also has been predicted by the activation of executive control systems during task encoding. The present study analyzed performance patterns in participants who could comprehend task regularity and those who could not at delayed recall. Specifically, the role of practice-based knowledge of sequence for individual awareness was focused on. A lateralized variant of the visual serial response time task (SRTT) comprising structured and random blocks was practiced in implicit conditions by 109 participants before and after 10-h retention, with explicit knowledge about covert sequence tested thereafter. Sequence learning was quantified using the normalized difference between response speed in regular and subsequent random blocks. Patterns of performance dynamics were evaluated using response speed, response variability, and error rate. Major results demonstrate that (1) All participants who became aware of the sequence (solvers), gained practice-based sequence knowledge at learning or after retention, (2) Such knowledge also was accumulated during learning by participants who remained fully unaware about covert task structure, (3) Only in explicit solvers, however, was sequence-specific learning accompanied by a prominent increase in performance variability. (4) Specific features and dynamics of performance patterns distinguished different cognitive modes of SRTT processing, each of which supported subsequent knowledge awareness. It is concluded that a behavioral precursor of sequence awareness is the combination of speeded sequence processing and increased performance variability, pointing to an interaction between implicit and explicit processing systems. These results may contribute to refine the evaluation of online and offline learning of tasks with dual structure, and to extend understanding of increased behavioral variability in both normal and pathological conditions.

Keywords: serial response time task, implicit learning, explicit knowledge, performance variance, insight

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INTRODUCTION

Continuous information input to the brain contains structured information of environmental regularities. If embedded in a multimodal flow, sometimes this information may not be perceived at encoding and remains out of awareness. The amazing property of the human brain is that structured regularities still can be discovered, either in the course of their repeated presentation (e.g., Frensch et al., 2002) or after a silent period of no exposure to structured information (e.g., Wagner et al., 2004). Conscious understanding of a covert rule leads to a qualitative change in behavior. Awareness of a covert rule may also lead to radically new strategies for problem solving and represents a particularly relevant aspect of creativity (Dietrich and Kanso, 2010).

Experimental conditions exploring gain of awareness typically use tasks with two levels of organization, overt and covert (Haider and Rose, 2007). The overt level is an instructed sensorimotor condition, requiring selective motor responding to pre-defined stimulus conditions. The covert level refers to the presence of a specific regularity in stimulus/response sequences that is unknown to participants. For example, in the typical variant of the serial response time task (SRTT, Nissen and Bullemer, 1987; Robertson, 2007), the overt level takes the form of a visual four-choice reaction task, since there are four response types, each of which is associated with one of four spatial locations of stimulus, and the instruction is to select the correct response as fast as possible. The covert level unknown to participants is the specific sequence of stimulus appearance (e.g., 12 stimuli), which is repeated continuously. In implicit learning conditions, participants may substantially improve performance for the structured sequence without having any expressible knowledge about it (Willingham et al., 1989), or may eventually become aware of it (Nissen and Bullemer, 1987; Ziessler, 1998; Willingham et al., 2000; Destrebecqz and Cleeremans, 2001, 2003). There has been a long standing debate on how this happens and why some but not all individuals have the capability to explicitly discover the regularity (e.g., Reder et al., 2009; Haider et al., 2012; Reber, 2013).

Major models posit that explicit knowledge (ExK) results from accumulated implicit knowledge of regularities. One possible mechanism is that the strength of implicit representations increases in the course of learning. Progressively enhanced implicit sequence representations either remain independent (Willingham et al., 1989) or can be accessed by awareness at a critical level of strength and distinctiveness (Cowan, 1995; Cleeremans and Jimenez, 2002). Alternatively, according to the Unexpected Event Hypothesis (Frensch et al., 2002), the progressive strengthening of implicit sequence representations improves task performance and fluency (Nissen and Bullemer, 1987; Dienes and Perner, 1999; Frensch et al., 2002; Scott and Dienes, 2009). As this occurs unintentionally, altered performance may trigger active conscious exploration of the sources for improvement. Conscious knowledge is thus generated by explicit examination of one's own behavioral alterations. Explicit search for event sequence also is the principal source of conscious knowledge in explicit learning conditions when subjects are instructed about the presence of regularities or when individual predispositions induce spontaneously cognitive strategies of active search (Robertson, 2007). Whether explicit awareness can emerge passively due to accumulation of implicit representations or it requires active search guided by cognitive control remains an open question.

Recent evidence has shown that individuals who go on to comprehend a hidden regularity (solvers[1]) encode task information differently from individuals who would not comprehend the regularity (non-solvers). Using event-related potentials Lang et al. (2006) have revealed that subsequent solvers, as compared to non-solvers, store the perceived events in memory to a greater extent and pay more attention to the presented stimuli and their sequence. Activation patterns of enhanced cognitive control in solvers have emerged at the very beginning of implicit learning, indicating a trait-dependent difference (Lang et al., 2006; Verleger et al., 2015). Functional MRI and electroencephalographic responses to covert structured information also have revealed a greater activation of executive control regions in future solvers as compared to non-solvers during implicit learning and at test after retention (Yordanova et al., 2009a; Darsaud et al., 2011). Together, these observations indicate that already during learning when task information is encoded, cognitive control mechanisms are more active in those participants who go on to comprehend task structure.

However, predictors of subsequent gain of explicit knowledge have not been clearly identified at the behavioral level. The objective of the present study was to analyze behavioral dynamics during implicit learning of the SRTT and characterize performance patterns in participants who would become solvers at subsequent delayed recall and those who would not. The major hypothesis was that if the ability to bring task knowledge to awareness depends on specific learning strategies, these strategies would be reflected in different performance modes and dynamics. Of special relevance was the question if sequence-specific knowledge acquired implicitly would be critical for subsequent awareness.

In the present study, participants trained a lateralized variant of visuo-motor SRTT implicitly (Verleger et al., 2015), with their explicit knowledge about a hidden sequence tested after a 10-h retention period. To evaluate the progression of learning, material was organized in three successive sub-sessions, in each of which blocks with regular sequences were preceded and followed by random blocks (Cohen et al., 2005). A fourth test sub-session was employed to characterize performance patterns after retention. Performance was evaluated by analyzing the dynamics of several parameters: response speed, performance variance, and error rate (ER) in regular and random blocks. As a marker for sequence-specific learning,

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[1] The term "solvers" is used in the present study to designate individuals who become aware of the hidden task regularity. In tasks, such as the number reduction task (NRT, Haider and Rose, 2007), conscious awareness of regularity typically takes the form of insight (a sudden awareness of the hidden rule). Although the conscious discovery of regularity is not abrupt in the SRTT, we adopt the same designation for explicit knowledge generation in the SRTT.

the difference between reaction times (RT) in regular and subsequent random blocks was used (Nissen and Bullemer, 1987). RT slowing in random blocks reflects sequence-specific knowledge because of the violation of sequence-based predictions emerging either implicitly (Nissen and Bullemer, 1987) or explicitly (Frensch et al., 2002) during regular block practice.

The present study provides an extended analysis of behavioral data which we reported in a paper on event-related potential predictors and correlates of explicit knowledge and implicit learning in the SRTT (Verleger et al., 2015). Compared to that report, the present paper offers the following. (1) A new classification of participants is introduced, distinguishing between "premature response" and "offline" solvers. (2) The achieved degree of sequence learning is assessed individually in each participant by statistical testing (rather than by median split of the entire group of participants). (3) Variability of RTs is analyzed as a marker of performance. (4) Behavioral data from all blocks in both the pre- and post-retention sessions (after 10 h) are analyzed.

MATERIALS AND METHODS

Participants

One hundred and eleven right-handed and healthy young adults were recruited from a larger study designed to investigate the effects of sleep on hemisphere-specific processing. From these, a total of 109 participants (55 female and 54 male) were used for the present study (mean age 22 years, range 18–31 years). According to the general study design, the retention period after which the gain of explicit knowledge was tested was either of continuous sleep or continuous wake. Accordingly, about half ($n = 53$) of participants performed the task in the morning and the other half ($n = 56$) in the evening (9 a.m. or 9 p.m.), followed 10 h later by a test session in the evening or in the morning, respectively. Also irrelevant to present study was the modulation of side of learning across participants. About half of them trained the task on the left side, and the other half – on the right side. The side of stimulus corresponded to the side of response. Retention and side of learning effects were not analyzed in the present study. All participants were right-handed (evaluated according to the Edinburgh Handedness Inventory, Oldfield, 1971), reported normal or corrected-to-normal vision and no history of chronic somatic, neurologic, or psychiatric disorders. During the experiment no drugs or psychoactive substances were used by the participants. Informed written consent was obtained before the experiment, and participants were paid a flat fee for participating of either 60€ (evening participants who had to stay overnight) or 20€ (morning participants). The study was approved by the Ethic Committee of the University of Lübeck, Germany.

Serial Response Time Task

In the study we used a lateralized modification of the SRTT suggested by Nissen and Bullemer (1987) – **Figure 1A**. Stimuli were programmed by means of the Presentation Software version 14.5 (Neurobehavioral Systems, Inc., Albany, CA, USA) and presented on a 17" computer monitor. Participants were instructed to maintain their gaze during the whole experiment to the middle of the monitor. As shown in **Figure 1B**, a fixation cross was permanently visible at screen center (black cross on a white screen). In each trial, two circles of approximately 3 cm^2 each (diameter of 1°) were presented, one in color and the other in gray, with equal displacement from the screen center of 4.4°. In a given session, the color circles appeared always right or always left, in one of the four colors green, blue, red, and yellow, always counterbalanced by a gray circle at the opposite side. The two circles were presented for 200 ms and the program waited until a button was pressed. If the response was correct, the cross changed after 200 ms for another 200 ms to bold, thus confirming the correctness of execution. Thereafter, the cross returned to its normal shape, and after 400 ms (800 ms after the response) the next color circle appeared. If the response was not correct, the cross did not change to bold and the next color circle did not appear until the correct button was pressed.

To control for eye fixation to the middle point of the monitor, an eye-tracker was used (Eye-Tracker 600 Series, Eyegaze Edge, LC Technologies, Inc., Fairfax, VA, USA). If fixation deviated from screen center by more than 2.6 cm at trial onset (visual angle larger than 1.3°), a large exclamation mark appeared for 2 s in the middle of the screen attracting gaze back to the center. Then the trial was restarted.

Throughout any session, responses were given with the same hand, ipsilateral to the constant side of the color stimuli, by pressing four different buttons. Participants were instructed to press the respective button on a response pad as quickly and accurately as possible. The response pad was designed in such a way that the position of the four buttons corresponded to the position of the fingers of a relaxed freely placed hand: the blue button (B) was exactly below the index finger, the red button (R) below the middle finger, the yellow button (Y) below the ring finger, and the green button (G) below the little finger.

Task structure followed the design used by Cohen et al. (2005). As displayed in **Figure 1A**, from participants' point of view, the learning session consisted of three parts of 280, 400, and 280 trials, altogether 960 trials, with self-terminated breaks between parts, and the test consisted of one part of 280 trials. One of the four colors appeared in each trial and had to be responded by pressing the appropriate key. Unknown to the participants, each part was a "sandwich" where the outer trials (first 50 and last 50: blocks 1, 4, 5, 8, 9, 12, 13, 16) followed a predetermined quasi-random series (but immediate repetitions of the same color did not occur) whereas the inner trials (180, 300, 180, and 180 in the four parts; blocks 2, 3, 6, 7, 10, 11, 14, 15) repeated a fixed sequence of 12 stimuli (15, 25, 15, and 15 times): B-R-Y-B-G-Y-R-B-Y-G-R-G (**Figures 1A,B**).

Performance Parameters

For each participant and block (12 learning and 4 test blocks) the following performance parameters were measured: (1) RT

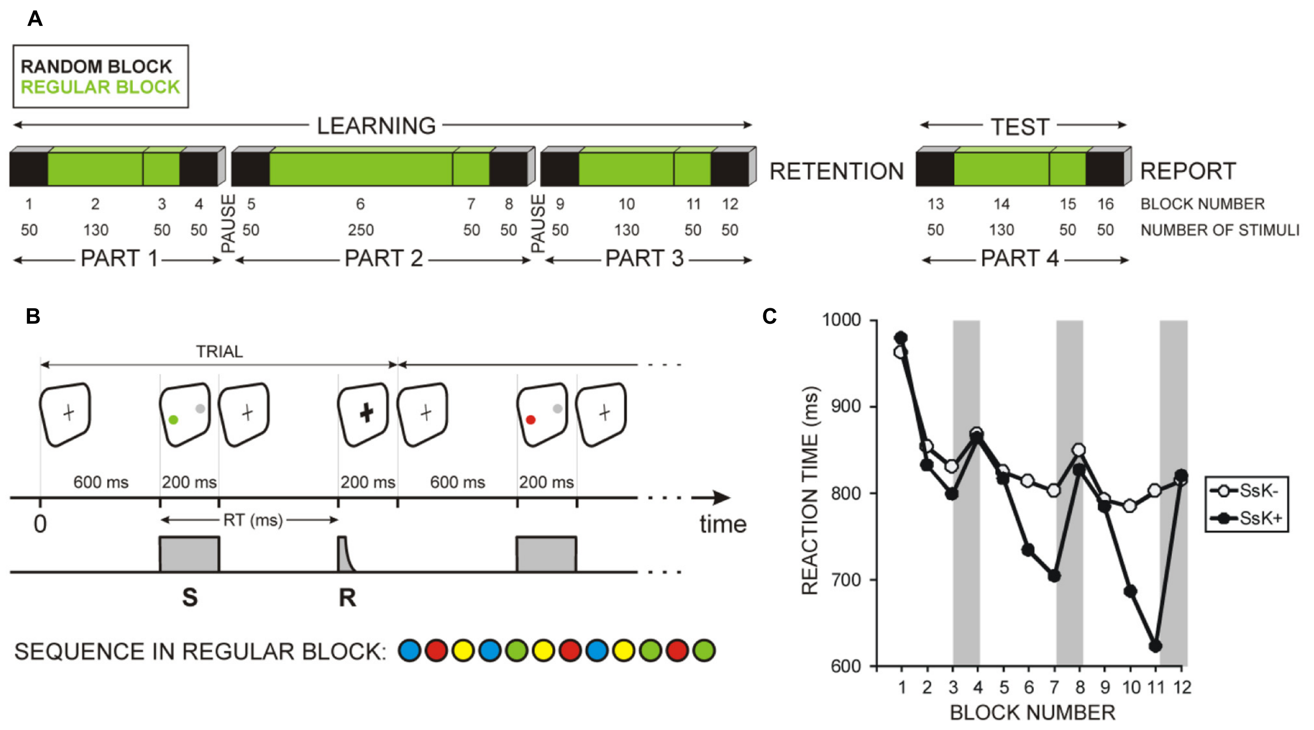

FIGURE 1 | Graphic illustration of the experiment. (A) Serial response time task (SRTT) was performed in four parts. Unknown to participants, each part was divided in four blocks, here numbered from 1 to 16 (BLOCK NUMBER), with the number of trials in each block indicated (NUMBER OF STIMULI). Blocks indicated in black contained random sequences of stimuli (RANDOM BLOCK); blocks indicated in green contained regularly ordered stimuli (REGULAR BLOCK). Participants practiced SRTT (LEARNING) and performed a TEST session after a 10-h retention period. **(B)** Schematic presentation of one trial of the SRTT. Color stimuli (S) required button-press responses (R) with the respective finger linked to each of the four colors. Sequence in regular blocks was composed of 12 items as indicated. **(C)** Mean reaction times (RTs) for the 12 learning blocks for two groups of participants: (i) who did not gain sequence-specific knowledge during learning (SsK−) and (ii) who acquired sequence-specific knowledge during learning (SsK+). Gray rectangles indicate sequence learning effects – RT difference between the last regular and the last random block in each part of the learning session.

to correct responses was calculated as the average of single correct responses. (2) Coefficient of variance (CV) was computed to reflect response variability by dividing standard deviation (SD) of RT by mean RT and multiplying the result by 100. (3) ER reflected performance accuracy and was computed as the percentage of commission error (pressing a wrong key) trials from all trials in a block. (4) For the sake of quantitative group analysis (Nissen and Bullemer, 1987; Robertson, 2009), the rate of RT change in the fourth random block relative to the preceding regular block in each part of the learning and test sessions was computed and used to represent a normalized measure of sequence-specific knowledge (SsK coefficient). (5) Number of correct premature responses in each block was measured. A response was classified as premature if it was faster than 150 ms (Yordanova et al., 2004). This criterion was chosen as being lower than simple reaction task time and indicating that processes which delay RT in four-choice tasks were not executed. Correct premature responses were used to select participants in a separate group.

Premature Response Group

If a participant had more than 10% premature responses in any of the blocks during learning, he/she was assigned to the premature response group (Prem-R) and was not included in offline explicit knowledge groups detailed below.

Explicit Knowledge Groups

After the test session, participants filled in a questionnaire to probe their explicit knowledge related to the hidden sequence in regular blocks. They were asked to write on paper any regular sequence they had noted. To quantify the gain of explicit knowledge in the SRTT, participants were scored from 1 to 5 in the following way. In case of no regularity being detected or no feeling of any pattern in the stimulation, the participant was scored with 1. Those who could recall a single sequence of 3–4 items were scored with 2; if they recalled two correct sequences of 3–4 items each, were scored with 3; those recalling a correct sequence of more than eight items were scored with 4, and participants who were able to report the whole sequence of 12 items were scored with 5. With regard to the statistical probability of reporting item sequence correctly, only those who were scored with 3, 4, and 5 were included in the group of explicit solvers (ExK+), whereas those scored with 1 and 2 formed the group of non-solvers (ExK−). It should be noted that ExK groups represent different amounts of explicit sequence knowledge at delayed recall following the test session after retention.

Sequence Learning Groups

Sequence-specific knowledge (SsK) analyzed here refers to the knowledge about the sequence during SRTT practice in implicit conditions, in contrast to ExK referring to delayed explicit recall of the sequence after retention. To classify participants, gain of SsK was computed at individual level. First, for each participant the Student *t*-test was applied to single-trials in order to determine if RT was significantly longer in the random block than in the preceding regular block (**Figures 1A,C**). In case of significant differences ($p < 0.05$) in the last part 3, the participant was classified as having (SsK+), or not having (SsK−) practice-based sequence knowledge. It is to be noted that SsK+ and SsK− distinction as defined here reflects sequence learning before retention.

Statistical Analysis

Each statistical parameter (RT, CV, ER, and SsK coefficient) was subjected to repeated measures analyses of variance (ANOVA). To assess performance dynamics in the course of learning, a within-subjects variable Part with 3 levels was included. A second within-subjects variable Regularity was used to contrast regular and random blocks. Performance dynamics at test was assessed using the Regularity variable for four blocks after retention (**Figure 1A**). The between-subjects variables in these analyses were ExK (ExK− vs. ExK+) and SsK (SsK− and SsK+). The objective was to compare performance patterns between participants who would subsequently become aware of the sequence by accounting for their knowledge about the sequence gained while they trained implicitly. Significant group effects and interactions were tested using MANOVA. To characterize learning strategies leading to premature reactions, the dynamics of performance parameters during learning was evaluated for participants with premature responses (Prem-R) in separate analyses with within-subjects variables Part and Regularity, and was compared to that of each other knowledge group using MANOVA (details are presented in the Results). Accordingly, the major SsK × ExK analysis did not include Prem-R participants but only sub-groups of the SsK × ExK combinations as shown in **Table 1**.

RESULTS

Table 1 presents the distribution of participants in different knowledge groups. Seven out of 109 participants were included in the premature response group. In four other participants, only sporadic premature responses were detected for the whole session of 960 trials. All Prem-R participants were aware of the sequence.

Effects of Sequence Learning on Performance Patterns in Explicit Solvers and non-Solvers

Dynamics of performance parameters during learning in four sub-groups defined by ExK × SsK interaction is illustrated in the left panels of **Figure 2**.

TABLE 1 | Distribution of participants in knowledge groups.

	ExK−	ExK+	Prem-R	Total number
SsK−	49	14	N/A	63
SsK+	30	9	7	46
Total number	79	23	7	109

ExK+, gain of explicit knowledge (solvers); ExK−, no explicit knowledge (non-solvers); SsK+, gain of sequence-specific knowledge during learning; SsK−, no sequence specific knowledge during learning; Prem-R, participants with premature responses during the learning session; N/A, not applicable.

Figure 2A demonstrates that RT in the regular blocks was faster [Regularity, $F(1/98) = 183.0$, $p < 0.001$] and, by definition, was significantly reduced in SsK+ participants [Regularity × SsK, $F(1/98) = 46.5$, $p < 0.001$]. SsK effect was significant in regular blocks of parts 2 and 3 [Part × Regularity × SsK, $F(2/196) = 16.5$, $p < 0.0001$; SsK effect in these blocks, $F(1/101) = 5.03$–15.9, $p = 0.03$–0.001]. Notably, RT did not differ between subsequent solvers and non-solvers, and ExK and SsK factors did not interact [$F(1/98) = 0.13$, $p > 0.7$] in any phase of learning ($p > 0.3$ for any interaction).

In contrast, **Figure 2B** demonstrates that CV depended on whether subsequent solvers (ExK+) have or have not gained sequence knowledge during learning. CV was significantly larger in solvers who acquired sequence knowledge during learning (SsK+/ExK+ sub-group) as compared to solvers who did not (SsK−/ExK+) and non-solvers with or without sequence specific knowledge [SsK × ExK, $F(1/98) = 4.3$, $p = 0.04$]. CV was substantially larger for regular blocks in solvers relative to non-solvers [Regularity × ExK, $F(1/98) = 13.3$, $p < 0.001$] and in the SsK+ than the SsK− group [Regularity × SsK, $F(1/98) = 7.2$, $p = 0.009$], but these effects stemmed from higher CV in only the SsK+/ExK+ group, i.e., explicit solvers who have gained knowledge about the sequence during learning [Regularity × ExK × SsK, $F(1/98) = 4.3$, $p = 0.04$; Regularity × ExK in SsK+, $F(1/38) = 7.8$, $p = 0.008$; in SsK−, $F(1/62) = 2.8$, $p > 0.1$]. No main or interactive effects of ExK and SsK were yielded for ER (**Figure 2C**).

By definition, SsK coefficient was larger in the SsK+ than SsK− group [$F(1/98) = 52.6$, $p < 0.001$] – **Figure 2D**. The difference between ExK+ and ExK− participants [$F(1/98) = 6.02$, $p = 0.015$] resulted from a greater SsK coefficient in the SsK+/ExK+ sub-group [SsK × ExK, $F(1/98) = 3.8$, $p < 0.05$]. Sequence learning in SsK+ participants progressed significantly faster if they, subsequently, went on to discover task regularity [Part × SsK × ExK, $F(2/196) = 3.4$, $p = 0.036$; SsK × ExK in parts 2 and 3, $F(1/101) > 4.0$, $p < 0.05$] – **Figure 2D**.

These results demonstrate that (a) only some of the participants gain practice-based knowledge of the sequence during learning, (b) not all participants who would, subsequently, become aware of the sequence gain practice-based knowledge about that sequence during initial exposure to task, (c) not all participants who learn the sequence through practice can bring this sequence-specific

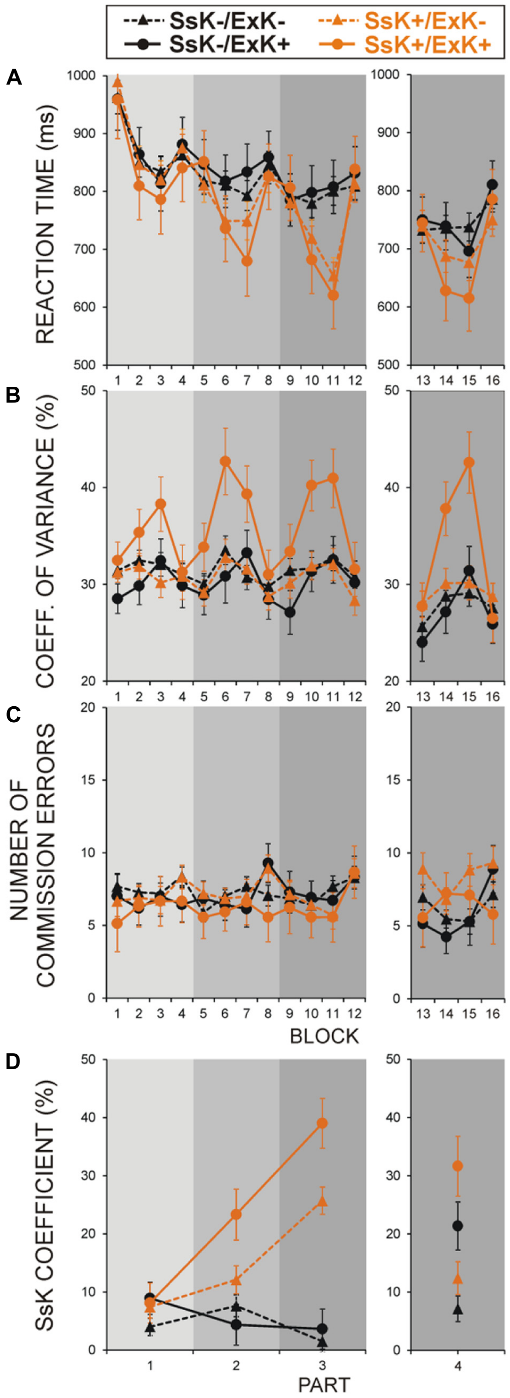

FIGURE 2 | Effects of sequence-specific knowledge (SsK) gained at learning and offline ExK on performance measures in four groups of participants: (i) non-solvers who did not acquire SsK at learning (SsK−/ExK−), (ii) offline solvers who did not acquire SsK at learning (SsK−/ExK+), (iii) non-solvers who acquired SsK at learning (SsK+/ExK−), and (iv) offline solvers who acquired SsK at learning (SsK+/ExK+). (A) RTs, **(B)** Performance variance, **(C)** Error rate (ER), **(D)** SsK coefficient. Gray rectangles indicate the four parts of experiment as shown in **Figure 1A**. Blocks 1–16 are designated as in **Figure 1A**. Left panels – learning session before retention (blocks 1–12, parts 1–3), right panels – test session after retention (blocks 13–16, part 4).

knowledge to awareness, (d) those participants who are able to bring sequence-specific knowledge to awareness are distinguished from all other performers by high performance variability.

Effects of Sequence Learning on Performance Patterns in Explicit Solvers and non-Solvers After Retention

Dynamics of performance parameters at test after retention (four blocks) in four sub-groups defined by ExK × SsK interaction is illustrated in the right panels of **Figure 2**. **Figure 2A** demonstrates that after retention, RT was faster in the regular than random blocks [Regularity, $F(1/98) = 91.4$, $p < 0.001$]. This effect was significantly more pronounced in ExK+ than ExK− participants (Regularity × ExK, $F(1/98) = 15.9$, $p < 0.001$] and in those who had gained sequence-specific knowledge during learning [Regularity × SsK, $F(1/98) = 16.0$, $p < 0.001$]. For those who had not (SsK−), a significant RT reduction in regular blocks after retention was yielded only in explicit solvers [Regularity × ExK in SsK−, $F(1/61) = 5.6$, $p = 0.02$; Regularity effect in the SsK−/ExK+ group, $F(1/13) = 8.1$, $p = 0.01$; regular block 3 vs. first random block in SsK−/ExK+, $p < 0.01$]. The four sub-groups did not differ in the first random block [SsK × ExK, $F(1/101) = 0.052$, $p > 0.8$], or in the last random block after retention [$F(1/101) = 0.004$, $p > 0.9$].

Figure 2B (right) demonstrates that after retention, CV was larger in regular than random blocks [Regularity, $F(1/98) = 56.1$, $p < 0.001$], in the ExK+ than ExK− group [Regularity × ExK, $F(1/98) = 21.4$, $p < 0.001$] and in the SsK+ than SsK− group [Regularity × SsK, $F(1/98) = 8.2$, $p = 0.005$]. As during learning, the latter effects were due mainly to the SsK+/ExK+ participants [Regularity × SsK × ExK, $F(1/98) = 10.4$, $p = 0.002$]. Among other sub-groups CV increased in the third regular block as compared to other blocks only in the SsK−/ExK+ participants [$F(3/39) = 5.5$, $p < 0.01$].

After retention, commission ER was higher in the regular blocks in participants who have acquired sequence knowledge at learning [Regularity × SsK, $F(1/98) = 6.5$, $p = 0.01$], whereas it was decreased in the SsK−/ExK+ group [Regularity × SsK × ExK, $F(1/98) = 4.3$, $p = 0.04$] – **Figure 2C**, right.

As indicated in the right panel of **Figure 2D**, sequence knowledge reflected by SsK coefficient after retention was greater in participants who have acquired this knowledge already during learning [SsK, $F(1/101) = 4.27$, $p = 0.04$], as well as in subsequent solvers [ExK, $F(1/101) = 19.8$, $p < 0.001$]. Consistent with RT finding, a prominent enhancement in sequence knowledge after retention is observed in the SsK−/ExK+ group.

These results show that (a) explicit solvers who had not learned the sequence by practice before retention (SsK−/ExK+) manifest sequence knowledge after retention, (b) increased performance variability in regular blocks after retention remains a distinguishing characteristics of explicit solvers who had accumulated sequence knowledge during learning before retention (SsK+/ExK+).

Performance Patterns of Premature-Response Participants

Performance parameters in the Prem-R group were assessed using ANOVA with within-subjects variables Part (three levels) and Regularity (regular vs. random blocks). Additionally, the Prem-R group was contrasted with other ExK × SsK knowledge sub-groups (SsK−/ExK−, SsK−/ExK+, SsK+/ExK−, and SsK+/ExK+) using MANOVA.

Number of premature responses is shown in **Figure 3A** to verify the selection of the premature response group and to demonstrate that premature responses (a) were generated in the regular blocks [Regularity, $F(1/6) = 7.5$, $p < 0.05$], and (b) appeared in the Prem-R groups already in the first part of learning and increased with learning progression [Part, $F(2/12) = 10.5$, $p = 0.005$; Regularity × Part, $F(2/12) = 10.3$, $p = 0.003$]. Accordingly, in the regular blocks of each part, the difference between Prem-R and other sub-groups was significant [$F(4/104) = 3.4$–86.4, $p = 0.009$–0.001] as indicated in **Figure 3A**.

As demonstrated in **Figures 3B–E**, following the dynamics of premature responses, RT, CV, ER, and SsK coefficient in Prem-R participants manifested significant variations in regular blocks. Accordingly, RT was substantially faster, CV was larger, and ER was smaller in the regular than random blocks [Regularity, $F(1/6) = 7.4$–36.3, $p = 0.03$–0.001], with these effects increasing with practice progression [Part, $F(2/12) = 7.9$–36.1, $p = 0.008$–0.001; Regularity × Part, ($F(2/12) = 5.1$–13.9, $p = 0.05$–0.002], which also was reflected by the SsK coefficient [Part, $F(2/12) = 14.1$, $p = 0.001$].

Consistent with these observations, significant differences between Prem-R and other four knowledge sub-groups groups were yielded for the regular blocks of learning parts 2 and 3 [$F(4/104) = 3.5$–34.9, $p = 0.04$–0.001], with effects not reaching significance for ER (**Figure 3**). Statistical differences between Prem-R and each other group indicated in **Figure 3** were corrected using Bonferroni procedure ($p = 0.03$–0.001). As an exception of these effects in regular blocks modulated by premature responses, response variability in the Prem-R group was significantly increased relative to other groups already in the first part of learning in random blocks when no premature responses were generated by any group [$F(4/104) > 3.5$, $p < 0.01$ for blocks 1 and 4]. Especially for the first random block of learning, CV was significantly larger in Prem-R as compared to each other group (Bonferroni corrected $p = 0.04$–0.004).

These results show that in Prem-R participants, sequence processing during learning is improved in terms of speed (fast/premature responses) and accuracy (decreased ER). Notably, these participants manifest increased performance variability at initial exposure to task.

DISCUSSION

Only some, but not all, individuals who train on tasks with dual structure, overt and covert, are able to consciously experience the covert task information. This individual ability has been associated with active cognitive control and enhanced consciousness during learning (Lang et al., 2006; Darsaud

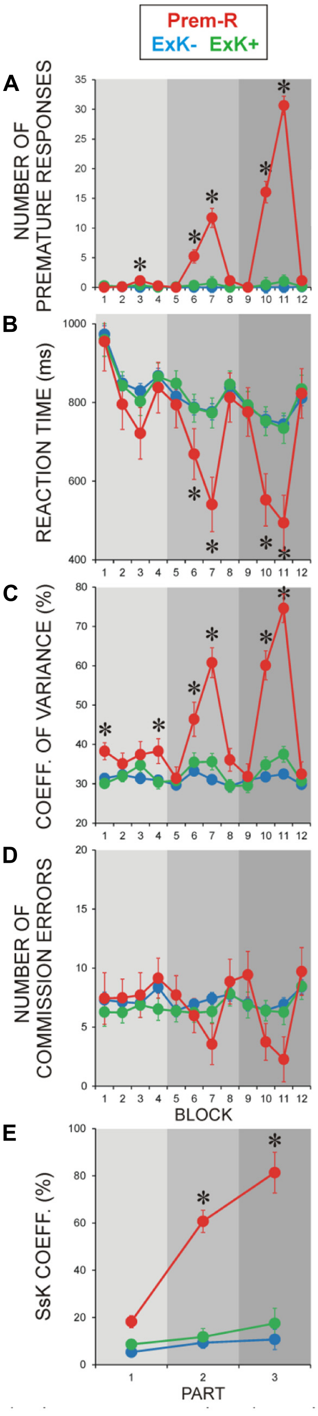

FIGURE 3 | Performance parameters during pre-retention learning in participants with premature responses (Prem-R). Offline explicit solvers (ExK+) and non-solvers (ExK−) are only illustrated to provide reference to Prem-R values and dynamics. **(A)** Number of premature responses during the learning session. **(B)** RTs, **(C)** Performance variance, **(D)** ER, **(E)** Sequence-specific knowledge (SsK) coefficient. Gray rectangles indicate three parts of experiment as shown in **Figure 1A**. Blocks 1–12 and parts 1–3 are designated as in **Figures 1A** and **2**. Asterisks indicate blocks, in which the Prem-R group differed significantly ($p = 0.05$–0.001) from each of the four SsK × ExK sub-groups. Between-group differences were tested by MANOVA.

et al., 2011; Verleger et al., 2015). On the other hand, initial accumulation of implicit sequence-specific knowledge is proposed to be critical for making the covert task information accessible by awareness (Nissen and Bullemer, 1987; Haider and Frensch, 2005, 2009; Haider and Rose, 2007). To assess if such implicit-explicit interactions shape specific learning strategies, the present study analyzed performance patterns in participants who could comprehend a hidden task structure and those who could not at delayed recall. Specifically, we focused on the predictive role of practice-based knowledge of regularity for subsequent awareness. Dynamic changes of a set of performance parameters were analyzed to characterize inter-individual differences in learning strategies at the behavioral level.

According to major results, (1) all participants who became aware of the sequence (solvers), manifested practice-based sequence knowledge, (2) notably, a similar sequence specific knowledge also was accumulated by participants who remained fully unware about the covert task structure, (3) only in explicit solvers, however, was sequence-specific learning accompanied by a prominent increase in performance variability, (4) specific features and dynamics of performance patterns distinguished different cognitive modes of SRTT learning, each of which supported subsequent knowledge awareness, but they all were uniquely characterized by increased performance variability.

The Role of Practice-Based Sequence Learning for Explicit Knowledge Generation

Practice-based knowledge of the sequence was evinced in all solvers. It was gained either during learning (SsK+/ExK+), or after retention (SsK−/Exk+). This observation confirms the notion that the formation of implicit associative sequence representations is crucial for subsequent awareness of regularity, emphasizing the role of the implicit-to-explicit transition (Frensch et al., 2002; Haider and Rose, 2007; Sun et al., 2007).

However, in a sub-group of participants (SsK+/ExK−), practice-based sequence learning also was found, but these participants remained fully unaware of SRTT regularity. This observation contributes to the debate on whether implicit and explicit systems can operate separately (Schacter, 1992; Reber and Squire, 1994; Seger, 1994; Destrebecqz and Cleeremans, 2001; Forkstam and Petersson, 2005; Abrahamse et al., 2010; Haider et al., 2011; Fu et al., 2013; Reber, 2013) by confirming the existence of stabilized implicit representations of the sequence independent from explicit representations of the sequence (Willingham et al., 1989). Also, this result shows that the mere formation of implicit representations during practice may not be a precursor of conscious comprehension. It may be argued that implicit representations had not reached a threshold or had strength insufficient to tag explicit processing (Cleeremans and Jimenez, 2002). However, the amount of sequence knowledge in the SsK+/ExK− sub-group did not differ from that of SsK+/ExK+ participants in the end of learning, nor did it differ from that of SsK−/ExK+ participants after retention. Hence, below-threshold strength of representations might not be the source of the inability of the SsK+/ExK− subjects to access explicitly accumulated implicit knowledge. It still may be that implicit sequence knowledge in this sub-group can further be strengthened with additional practice, so that access to the explicit system would be reached at a later stage. However, the reduction in sequence knowledge after retention in this sub-group (as seen in **Figure 2**) does not support this possible development. Nor is it certain that offline learning during retention can strengthen additionally implicit sequence representations (Song et al., 2007; Nemeth et al., 2010; Al-Sharman and Siengsukon, 2014). Thus, a substantial gain of implicit sequence specific knowledge may not be on its own a reliable precursor of subsequent awareness. Rather, as will be discussed below, the operationalization of implicit practice-based representations within explicit system functioning appears to be critical.

Comparing sequence learning in explicit solvers and non-solvers shows that in implicit learning conditions, practice-based sequence knowledge can be acquired in different ways. Sequence learning in non-solvers (SsK+/ExK−) emerged on the background of speeded and highly stable and fluent overt performance pointing to proceduralization and automatization of behavior. In contrast, sequence learning in solvers (SsK+/ExK+) was marked by similarly fast but highly variable responses in regular blocks, which also was observed in the SsK−/ExK+ solvers after retention. In explicit solvers with premature responses, performance variability was markedly enhanced by highly speeded or premature reactions in regular blocks (**Figure 3**), Although different mechanisms may be responsible for raised variance in separate sub-groups of solvers (Frensch et al., 2002), the present results are relevant in showing that speeded sequence processing alone may not differentiate the overt level of processing in subsequent solvers and non-solvers. Rather, increased response variability emerging in parallel with advanced sequence learning provides a distinction. From this perspective, the unexpected experience of variation (e.g., disruption, slowing, or conflict) within a fluent proceduralization may generate a neurophysiological signal of mismatch which may act as an efficient online or offline trigger of the explicit processing system.

Sources of Delayed Explicit Knowledge Generation

Present results reveal that the combination of practice-based sequence learning and increased performance variability provides a marker for conscious comprehension of the sequence. Variants of this combination helped to identify three different types of processing strategies during learning, all of which were associated with the ability to bring hidden task regularity to awareness. These different processing strategies were expressed in the groups of Prem-R solvers, and solvers who did (SsK+/ExK+) or did not (SsK−/ExK+) acquire sequence knowledge at pre-retention task practice.

Online Solvers

Haider and Frensch (2005, 2009) and Haider and Rose (2007) propose that in tasks with dual structure (overt and covert), conscious comprehension of the covert rule leads to an abrupt qualitative alteration of behavior, which is marked by a sudden substantial decrease in performance speed (RT drop). Frensch et al. (2002) observed in the number reduction task (NRT) that RT variance of participants who gained insight to the covert rule, increased shortly before they became aware of the rule. This phenomenon was linked to the Unexpected Event Hypothesis and to the switch to an intentional active search for regularities in the stimulus/response material, i.e., to the functioning of a new task-(meta-)representation engaging cognitive control and explicit processing (Haider et al., 2011).

In the currently employed SRTT version, a sub-group of participants (6.4%) produced extremely fast responses faster than 150 ms analogous to "RT drop." Since this response speed corresponds to simple RT (Yordanova et al., 2004), it is indicative for the fact that processes delaying RT in four-choice tasks (stimulus identification, stimulus-response integration, and response selection), are not executed. This can only be achieved if participants know in advance which stimulus will appear on the next trial, or if they are in a stage of highly advanced implicit learning of the sequence. The presence of premature responses already in the first part of the learning session (**Figure 3A**) points to explicit rather than implicit origin of extremely speeded reactions. Hence, individuals from this group have discovered the presence of regularity during practice (online solvers) and have changed their mode of task processing from implicit to explicit (Robertson, 2007, 2009). This is confirmed by the unique pattern in these participants characterized by a dramatically speeded accumulation of sequence knowledge along with improvement of accuracy.

Another intriguing behavioral characteristic of this group was the increased performance variability. While increased variability in regular blocks can be explained with premature responses no such responses were generated in the first random block of learning, nor was RT specifically delayed in this group. Therefore, increased variability in the beginning of learning may not be directly related to checking of a perceived regularity (Frensch et al., 2002), nor may it index distractibility (Yordanova et al., 2011). Rather, this initial performance instability points to a different mode of processing in both random and regular blocks, independently of exposure to sequence. With regard to neurophysiological evidence for enhanced controlled processing during task encoding in subsequent solvers (Lang et al., 2006; Yordanova et al., 2009b; Darsaud et al., 2011) the unstable performance of online solvers identified here appears to reflect an active self-induced or self-instructed search for regularity. In line with previous reports (e.g., Nissen and Bullemer, 1987; Wagner et al., 2004; Haider et al., 2005; Yordanova et al., 2008) these results demonstrate that part of the individuals possess an inherent attitude to actively explore environmental structure.

Knowledge Awareness and Practice-Based Sequence Learning

In 8.2% of participants, a cognitive strategy was identified which promoted awareness on the basis of accumulated practice-based sequence knowledge. This strategy is represented by the SsK+/ExK+ sub-group. No signs of explicit sequence comprehension during learning (premature responses) were detected in this sub-group. On the background of progressive sequence learning, these participants presented with a unique performance feature, i.e., an enhanced performance variance only in the regular blocks, not in the random blocks, which occurred already with initial exposure to regularity in the first learning session. Also, enhanced variance to regularity was not synchronized with implicit gain progression in the course of learning. On these grounds, it may be suggested that in this sub-group, unstable performance in regular blocks reflects a strong penetration of an implicit model in a fragile form. On the other hand, it has been shown that during SRTT training, subjects do not learn uniformly all parts of a sequence (Schlaghecken et al., 2000; Wilkinson and Shanks, 2004). During exposure to regularity, parts of sequence can be consciously detected, while other parts remain a mixture of implicitly learned and unlearned fragments of the sequence (Miyawaki et al., 2005). It can be therefore also proposed that in this sub-group, increased variance to regular items results from partial explicit knowledge. This suggestion is consistent with previous observations (Yordanova et al., 2009a), according to which subsequent solvers in the NRT were characterized by a significantly larger RT variance of responses to predictable items, corresponding to a stronger activation of cognitive control brain regions (Darsaud et al., 2011).

Knowledge Awareness Promoted by Offline Consolidation of Procedural Knowledge

A third sub-group of explicit solvers identified in the present study (12.8%) comprised participants who did not manifest enhanced performance variance and did not learn the sequence (SsK−/ExK+), thus showing a cognitive mode of processing very similar to that of explicit non-solvers who did not learn the sequence by practice (SsK−/ExK−). Major precursors of explicit knowledge generation in this sub-group, however, emerged after retention, when a substantial gain in sequence knowledge occurred along with increased performance variance. Obviously, offline retention was critical for knowledge awareness in this sub-group (Wagner et al., 2004; Yordanova et al., 2008, 2009a,b, 2010). As indexed by high accuracy and exclusively stable performance at learning, these participants seem to have developed a fundamental focus on the overt level of SRTT, with overwhelming processing of stimulus-response (S-R) associations. This assumption is supported by another study of the same data set (Verleger et al., 2015). Increased parietal P3 components were yielded during SRTT learning in such participants reflecting intensive learning of S-R and R-S relationships, or additional testing of the feedback value of each stimulus (Verleger et al., 2015). Thus, current results suggest that delayed awareness of sequence can emerge on the base of firmly learned S-R pairs, i.e., consolidated overt SRTT level (Robertson, 2009; Yordanova et al., 2009a; Diekelmann and Born, 2010), and that the implicit penetration of regularity can act on consolidated S-R pairs. It remains to be established why offline consolidation was efficient in promoting a subsequent integration of pairs in higher-order structures only in individuals with enhanced cognitive processing indexed by large P3 components (Verleger et al., 2015).

CONCLUSION

(1) In implicit learning conditions, the formation of practice-based sequence representations precedes subsequent awareness of regularity. (2) Implicit sequence-specific knowledge alone is not a precursor of explicit knowledge generation. (3) A behavioral precursor of subsequent awareness is the combination between practice-based sequence knowledge and increased performance variance, pointing to an interaction between implicit and explicit processing systems during task practice. (4) Implicit-explicit interactions during task practice may have different origins: (a) inherent individual attitude to active exploration of environmental structure, (b) comprehension of fragmented sequence, or (c) interfering implicit representations. All cognitive modes contributing to awareness are marked by increased performance variability. These results may (i) refine the evaluation of online and offline learning of tasks with dual structure, in particular SRTT, and (ii) extend our understanding of increased behavioral variability in both normal and pathological conditions.

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Dissociative states in dreams and brain chaos: implications for creative awareness

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This article reviews recent findings indicating some common brain processes during dissociative states and dreaming with the aim to outline a perspective that neural chaotic states during dreaming can be closely related to dissociative states that may manifest in dreams scenery. These data are in agreement with various clinical findings that dissociated states can be projected into the "dream scenery" in REM sleep periods and dreams may represent their specific interactions that may uncover unusual psychological potential of creativity in psychotherapy, art, and scientific discoveries.

Keywords: dreams, dissociation, self-organization, chaos, creativity

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Introduction

A particular unexplained question is whether it may be possible for an individual to have a "transcendental experience" in which consciousness transcends its own symbolic self-understanding and abstract thinking and how these experiences may be related to particular aspects of consciousness and their complex organization in the brain. Recent findings indicate that conscious states can be described as representations of brain states and related to dynamics of large-scale neuronal networks (Freeman, 1991, 1999, 2000; Singer, 2001; Varela et al., 2001; Rees et al., 2002; Fingelkurts et al., 2010, 2013; Bob, 2011; Fingelkurts and Fingelkurts, 2012).

According to some recent theoretical viewpoints subjective experience can be represented in the brain by a "cerebral mental field" which refers to the mind as a system property related to the synchronized activities of large numbers of neurons (Libet, 2006). These specific complex processes linking the brain and its cognitive "mental field" may help to describe relationships between subjective experience and brain activation patterns on various functional levels of organization (Freeman, 1991, 1999, 2000; Melancon and Joanette, 2000; Varela et al., 2001; Korn and Faure, 2003). In addition, these findings show that not only brain generates consciousness, but also consciousness affects the brain. This complex organization of subjective mental experiences plays a role in spatio-temporal activities of the brain, which via various feedback loops are associated with the spatial-temporal organization of the mind processes (Freeman, 1991, 1999, 2000; Fingelkurts et al., 2010, 2013; Bob, 2011; Fingelkurts and Fingelkurts, 2012; Bass, 2014; Tang et al., 2015).

In this context, recent findings indicate that distributed patterns of neuronal activities are specifically linked within neural assemblies that tend to create coherent systems, which enable mental representations related to perceptual and cognitive functions, memory processes, and conscious awareness (Freeman, 1991; Singer, 2001; Rees et al., 2002). In addition, according to the recent evidence these neural mechanisms that enable conscious integration are significantly affected by various stressful and traumatic experiences that may determine dissociation of conscious awareness and memory (Li and Spiegel, 1992; Putnam, 1997; Bob, 2003; Spiegel, 2012).

Dissociative States in Dreams

Dissociative states usually emerge as a disconnection and switch between different mental states due to a disconnection between memories related to traumatic or stressful experiences that disturb conscious awareness and experience of the self (Li and Spiegel, 1992; Putnam, 1997; Bob, 2003; Spiegel, 2012). In this context, dissociation can be defined as a partial or total disconnection between memories of the past, awareness of identity and of immediate sensations, and control of bodily movements often resulting from traumatic experiences, intolerable problems, or disturbed relationships (Li and Spiegel, 1992; Bob, 2003; Colman, 2003). Due to this disconnection of memory and identity dissociation is related to disability to integrate some mental contents into conscious awareness (Bernstein and Putnam, 1986). In agreement with new DSM-V criteria, dissociation may be defined: "as a disruption of and/or discontinuity in the normal, subjective integration of one or more aspects of psychological functioning, including—but not limited to—memory, identity, consciousness, perception, and motor control" (Spiegel, 2012; American Psychiatric Association, 2014).

Dissociative mental states also manifest during dreams and may be typically related to discontinuities and shifts in dream scenes, which according to some psychological studies of dreams may specifically manifest in pathological processes related to nightmares and recurrent dreams linked to traumatic experiences (Ferenczi, 1934; Levitan, 1980; Hartmann, 1998; Bob, 2004; Schonhammer, 2005). Intriguing relationships between dreams and the dissociative states were also reported in cases of the so-called "alter personalities" in multiple personality disorder (MPD), which may manifest on parallel levels in dreams and during personality alterations in hypnosis (Jeans, 1976; Marmer, 1980a,b; Salley, 1988; Putnam, 1989; Brenner, 1996, 1999, 2001; Bob, 2004). For example, Barrett (1994, 1995, 1996) reported some cases of MPD in which alter personalities manifested in dream scenes. These case studies suggest that dream "personalities" may manifest as hallucinated projections of various aspects of the fragmented self that may be understood as prototypes of these alter personalities (Bowers and Brecher, 1955; Watkins and Watkins, 1979–1980; Merskey, 1992; Rickeport, 1992; Watkins, 1993; Lynn et al., 1994; Barrett, 1995; Bob, 2004). In this context, Bowers and Brecher (1955) reported that fragmented aspects of the self, very similar to altered personalities in MPD, may manifest during hypnosis also in individuals without multiple personality structures and also they may be observed in dreams and associations using Rorschach test. Taken together these reported studies suggest that dissociative mental states may be projected as specific types of hallucinatory experiences during dreams and may be identified as parts of dream scenes (Gabel, 1989; Hartmann, 1998; Bob, 2004). An important implication of these data is that dreaming processes may represent a conscious reflection of dissociative states represented during memory processing in REM sleep (Gabel, 1989; Rotenberg, 1992; Bob, 2004; Eisser, 2005; Stickgold and Walker, 2005).

Dreams and Brain Chaos

Recent findings indicate that some modalities of awareness and attention used for self-monitoring and for the internal explorations of one's consciousness such as dreams, meditation and various forms of creative awareness may be at certain levels of brain functions understood using theories of non-linear dynamics, chaos and self-organization (Freeman, 1991, 1999, 2000; Elbert et al., 1994; Melancon and Joanette, 2000; Bob, 2003, 2011; Korn and Faure, 2003; Fingelkurts et al., 2013).

In the scientific history, the chaotic processes were for the first time documented in the last years of 19th century in the work by Poincaré (1908/1998). In his "Science and method" Poincaré (1908/1998, p. 68) wrote: "A very small, unnoticeable cause can determine a visible very large effect; in this case we claim that this effect is a product of random . . .".

In the dynamic state of chaos very small changes in a system can result to very large differences in the system's behavior (the so-called butterfly effect, which metaphorically means that the flapping of a butterfly's wings in one part of the world later may cause a tornado in a distant part of the world). Chaos represents a dynamic pattern of activity that occurs when a system involves a large number of interlinked and simultaneously active states, which can lead to self-organization (Freeman, 1991, 2000; Elbert et al., 1994; Korn and Faure, 2003; Bob, 2015).

Seminal contributions to this field of research reported Freeman (Freeman, 1991, 1999, 2000; Elbert et al., 1994; Bob, 2011), who was particularly interested to explore how brain generates cognitive processing, intentionality, and meaning. In his research Freeman found that brain activities may manifest chaotic behavior. Freeman also proposed that chaos could underlie basic forms of collective neural activity in perceptual processing including ability to access memorized sensory patterns and learning of novel sensory information. In cognitive processes chaos may explain brain ability to respond flexibly to the outside world and to generate novel activity patterns that are subjectively experienced as "novel" ideas that enable complex dynamic behavior of the brain and intentional behavior (Freeman, 1991, 1999, 2000).

Recent findings indicate that deterministic mechanisms of brain activity as well as chaotic neural patterns are important for brain functioning (Freeman, 1991, 1999, 2000; Elbert et al., 1994; Birbaumer et al., 1995; Kantz and Schreiber, 1997; Bob, 2011). In this context, mental states and brain activities related to intentional goals are predictable and deterministic. On the other hand brain processes related to great sensitivity to very small changes, mainly in initial stages of a neural processes, seem to be characterized by chaotic neural activities and mental states, for example during free floating divergent thinking or search related mental events (Freeman, 1991, 1999, 2000; Elbert et al., 1994; Globus and Arpaia, 1994; Birbaumer et al., 1995; Faure and Korn, 2001; Meyer-Lindenberg et al., 2002; Bob, 2011; Yoruk and Runco, 2014). These chaotic brain activities with increased sensitivity to "initial conditions" underlying novel trends in brain processes are related to a very large number of interacting and interlinked neural states that are sensitive and unstable because of a competition of many neural patterns (Freeman, 2000; Korn and Faure, 2003). According to these findings chaos may enable flexible brain responses to some external stimuli associated with novel neural activities, behavior and cognitive processing, for example experiences of original ideas and creativity (Skarda and Freeman, 1987; Freeman, 1991, 2000, 2001; Elbert et al., 1994; Melancon and Joanette, 2000; Korn and Faure, 2003; Bob, 2011). Chaotic states in the brain may manifest in various cognitive processes as for example in dreams (Kahn and Hobson, 1993; Kahn et al., 2000, 2002; Bob, 2011; Kahn, 2013), dissociative states (Pediaditakis, 1992; Putnam, 1997; Sel, 1997; Bob, 2003) and may characterize specific processes in development of mental disorders, as for example in depression or schizophrenia (Gottschalk et al., 1995; Huber et al., 1999; Paulus and Braff, 2003; Bob, 2011).

Chaotic brain states are usually related to activities in various independent regions that process information in parallel distributed mode (Tirsch et al., 2004). This parallel distributed processing may manifest in transient states and fluctuations of increased or decreased complexity that in cases of low associated strength among the parallel distributed information subsystems may lead to dissociated mental states (Mc Clelland et al., 1986; Li and Spiegel, 1992; Butler et al., 1996; Bob, 2003). Due to these decreased levels of association between some information processes, dissociation manifests as disturbed continuity between interacting mental states (Li and Spiegel, 1992; Bob, 2003).

Dream scenes mainly occur in the REM sleep and include mental images, thoughts, sounds, and other sensory experiences in various sequences that may be episodically disturbed by discontinuous shifts in dream narratives (Kahn and Hobson, 1993; Faw, 1997; Kahn et al., 1997, 2000, 2002; Stickgold et al., 2001; Hobson and Pace-Schott, 2002; Kahn, 2013). According to some findings neural correlates of these discontinuous shifts in a dream scenery are rapid shifts in neural patterns related to self-organized neural activities, mainly associated with activities of cholinergic pontogeniculoocipital (PGO) systems (Hobson and McCarley, 1977; Quattrochi et al., 1989; Hobson, 1990; Kahn and Hobson, 1993; Stickgold et al., 1994, 2001; Kahn et al., 1997, 2000, 2002; Kahn, 2013). In addition, there is also evidence that the PGO activity is correlated with increased firings in the visual cortex and lateral geniculate bodies participating in formation of images (Callaway et al., 1987; Singer, 1989; Kahn and Hobson, 1993; Porte and Hobson, 1996; Stickgold et al., 2001; Kahn, 2013). During these self-organizing processes brain responses may become very sensitive with respect to very small stimuli which may lead to chaotic bifurcations that cause rapid shifts in patterns of neural activities related to increased cholinergic and decreased aminergic input onto forebrain structures (Kahn and Hobson, 1993; Stickgold et al., 1994; Kahn et al., 2000, 2002; Kahn, 2013). According to recent findings these chaotic processes may be characterized by significant transitions of dream objects and sceneries due to a competition and interference of various dream images, which lead to dream discontinuities and multiple transitions of neural firing patterns (Tender and Kramer, 1971; Kaczmarek and Babloyantz, 1977; Elazar and Hobson, 1985; Rotenberg, 1992; Kahn and Hobson, 1993; Kahn et al., 1997, 2000, 2002; Kahn, 2013).

Dreams, Conscious Awareness, and Novel Ideas

Reported findings suggest that dreams may reflect dissociative mental states that especially manifest as discontinuous jumps in the dream scenery (Salley, 1988; Gabel, 1989; Bob, 2004), which in a similar way as dissociative states during waking may be related to chaos and self-organization in the brain (Pediaditakis, 1992; Putnam, 1997; Sel, 1997; Bob, 2003, 2011). These findings are in accordance with experiences and case studies in psychotherapy, which indicate that dreams are not random processes and may be meaningful for self-discovery and personal growth (Jeans, 1976; Marmer, 1980a,b; Salley, 1988; Barrett, 1994, 1995, 1996; Brenner, 1996, 1999, 2001; Bob, 2004).

A specific feature of chaotic neural states is that they can generate novel patterns of neural activities and novel synaptic connections, which may link less associated or dissociative mental states into a coherent whole (Kahn and Hobson, 1993; Kahn et al., 2000). For example, several findings suggest that high complexity and self-organization manifest also during creative divergent thinking (Combs, 1996; Mölle et al., 1996). Specifically in the REM sleep these integrative processes support "binding" functions of dreams, which connect dream images coherently together that enables novel creative unity of conscious experience (Revonsuo and Tarkko, 2002). These findings suggest that dreams may reflect new integrations of dissociated mental states related to traumatic and stressful experiences and may also increase creative potentialities in various cases of artistic inventions, scientific discoveries and deep insights related to meta-cognitive, transcendental or religious experiences reflecting certain forms of "preconscious" or "unconscious" intelligence (Haule, 1984; Barrett, 1993; Strunz, 1993; Baylor, 2001; Schaverien, 2005; Louchakova, 2006; Edwards et al., 2013; Dresler et al., 2015).

Conclusion

Chaos and self-organization manifest in brain and cognitive functions and may be specifically related to dissociative states characterized by rapid shifts between disconnected mental states that in the case of dreams are likely specifically related to PGO bursts of neural activity (Kahn and Hobson, 1993; Putnam, 1997; Bob, 2003, 2011; Korn and Faure, 2003; Kahn, 2013).

Although the current literature and evidence about these links between dreams and dissociated states are limited, they provide useful explanatory scheme for future research that could explain more detailed connections of self-organizing theory of dreams and dissociative states. For example, Tart (2009) suggests that hypnotic techniques provide a useful framework for experimental studies of dreams and other clinical data show that also dreams in patients who experienced serious traumatic events could open new perspectives in this research (Bob, 2004; Rotenberg, 2014). These studies may also provide new theoretical framework for understanding of connections between dreams and brain functions related to unusual creative potential of unconscious mental processing as well as important findings for psychotherapy that using "dream analysis" may open novel insights and creativity in individual life and help to resolve traumatic experiences linked to various mental disorders.

Taken together these data suggest a perspective for further research that dissociated mental states may be projected into a dream scenery during REM sleep and dreams may represent specific interactions of dissociated contents, which may create the content of the dream (Salley, 1988; Gabel, 1989; Bob, 2004). These data also suggest that neural chaotic states during dreaming may represent underlying neural processes that enable new integration of dissociated contents of memory which may generate novel ideas, insights and other creative conscious states.

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Comparing personal insight gains due to consideration of a recent dream and consideration of a recent event using the Ullman and Schredl dream group methods

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There have been reports and claims in the psychotherapeutic literature that the consideration of recent dreams can result in personal realizations and insight. There is theoretical support for these claims from work on rapid eye movement (REM) sleep having a function of the consolidation of emotional memories and the creative formation of connections between new and older memories. To investigate these claims, 11 participants (10 females, one male) reported and considered a recent home dream in a dream discussion group that following the “Appreciating dreams” method of Montague Ullman. The group ran 11 times, each participant attending and participating once. A further nine participants (seven females, two males) reported and considered a recent home dream in a group that followed the “Listening to the dreamer” method of Michael Schredl. The two studies each had a control condition where the participant also reported a recent event, the consideration of which followed the same technique as was followed for the dream report. Outcomes of the discussions were assessed by the participants on the Gains from Dream Interpretation (GDI) scale, and on its counterpart, the Gains from Event Interpretation scale. High ratings on the GDI experiential-insight subscale were reported for both methods, when applied to dreams, and for the Ullman method Exploration-Insight ratings for the dream condition were significantly higher than for the control event condition. In the Ullman method, self-assessment of personal insight due to consideration of dream content was also significantly higher than for the event consideration condition. The findings support the view that benefits can be obtained from the consideration of dream content, in terms of identifying the waking life sources of dream content, and because personal insight may also occur. To investigate the mechanisms for the findings, the studies should be repeated with REM and non-REM dream reports, hypothesizing greater insight from the former.

Keywords: dreams, insight, sleep, REM sleep, psychotherapy, psychopathology

Introduction

There have been reports and claims in the psychotherapeutic and psychoanalytic literature that the consideration of recent dreams can result in personal realizations and insight (e.g., Freud, 1953; Blechner, 2001; Blass, 2002; Lippmann, 2002). Edwards et al. (2013) addressed these claims in a non-clinical dream interpretation group that followed the dream group method of Montague Ullman (1996). Self-ratings of gains from participation in the dream group sessions, assessed by the Gains from Dream Interpretation (GDI) questionnaire, showed that the Ullman technique is an effective procedure for establishing connections between dream content and recent waking life experiences, even though wake life sources were found for only 14% of dream report text. The mean Exploration-Insight subscale score on the GDI questionnaire was very high (8.17 on a scale from 1 to 9) and comparable to outcomes on the same measure from sessions using the well-established Hill (1996) therapist-led dream interpretation method. The current study follows the method used in the Ullman dream group study of Edwards et al. (2013) but includes also as a control condition the consideration of a report of a recent personally significant event, using the same interpretation technique as for the recent dream. A second technique for considering dreams, that of Schredl (2007, 2011), is also used for a separate sample of participants, again with an event interpretation control condition.

There are theoretical and empirical reasons to support the proposal that salient waking life events and concerns may appear in dreams and that the consideration of that dream content may result in realizations or insight about one's life circumstances. Edwards et al. (2013) review evidence that dreams reflect the current waking life concerns or recent personally significant waking life events of the dreamer. This reflection follows from the preferential incorporation of emotional waking-life experiences (Schredl, 2006; Malinowski and Horton, 2014; van Rijn et al., 2015), and concerns (Domhoff, 2003; Selterman et al., 2012) into dreams. This preferential incorporation can result in dream content being affected by psychopathology (Schredl and Engelhardt, 2001), acute mood and well-being (Chivers and Blagrove, 1999; Schredl, 2003), and major life circumstances such as pregnancy (Lara-Carrasco et al., 2013) and bereavement (Black et al., 2014). These continuities in the relationship between dream content and waking life experiences have led to the view that dreaming may be adaptive (Hartmann, 1995; Ruby, 2011), and one characteristic of adaptation that has been proposed for dreaming has been the ability to elicit insight (Maquet and Ruby, 2004; Cai et al., 2009). This proposal can be justified by the following three premises.

Firstly, that sleep, and in particular rapid eye movement (REM) sleep, is involved in functional reorganization of the brain that subserves emotional memory consolidation (Nishida et al., 2009; Dang-Vu et al., 2010; Wamsley and Stickgold, 2011; Groch et al., 2013, 2015), emotion regulation (Walker and Van der Helm, 2009), and cognitive insight (Wagner et al., 2004; Darsaud et al., 2011). During REM sleep (as compared to wakefulness), decreased activity in the dorsolateral prefrontal cortex and temporo-parietal junction, increased or maintained activity in the limbic system (notably amygdala, medial prefrontal/anterior cingulate, hippocampus, and parahippocampal cortex) and modification of functional connectivity between brain regions (Maquet et al., 1996, 2005; Nofzinger et al., 1997; Braun et al., 1998), may enable a different organization of cognition, favoring notably the triggering of emotional over neutral memories, the processing of spontaneous over actively selected thoughts, and an associative rather than a mainly logical mode of thinking.

Secondly, that functional reorganization and plasticity during sleep is reflected in dream content (Wamsley et al., 2010a,b; Wamsley and Stickgold, 2011), which may explain some famous claims of insight inspired by a dream (Maquet and Ruby, 2004; Cai et al., 2009). This fits with the suggestion of Perogamvros et al. (2013) that sleep and dreaming enable the offline reprocessing of emotions, associative learning, and exploratory behaviors, resulting in improved memory organization, waking life emotion regulation, social skills, and creativity.

Thirdly, and more speculatively, that the consideration of that dream content after waking can augment the associative and reorganizational processes that occur in sleep, and in wake. This premise has two components, both derived from the work of Freud (1953), that the process of free-association to the elements of a dream leads back to the precipitating sources of the dream (Baylor and Cavallero, 2001), and that the waking life free-associative process is similar to the flexible and creative cognitive processes suggested to be occurring during REM sleep (Walker et al., 2002).

Assessing Insight Resulting From the Consideration of Dreams

The main empirical work on personal insight due to dream interpretation is that of Clara Hill, who uses one-to-one sessions with a therapist following Hill's (1996). Exploration-Insight-Action model of dream interpretation. That work shows that personal insight from working with a recent dream is greater than when working with a report of a recent waking life event or with a dream of another person (Hill et al., 1993). However, that method is designed for use within psychotherapy, whereas our aim is to utilize methods designed for the lay (although skilled) use of considering dreams, in a group of people. For the current investigation, the Ullman and Schredl dream group methods were chosen, because they are designed for lay rather than psychotherapeutic use, because psychotherapy training is not needed for group leaders to run the sessions, and because there is published academic backing for the rationales for the two methods.

The Ullman (1996) dream group method aims at safe self-realizations and explorations rather than directed therapy. The procedure, detailed below, allows for the full describing of as much as can be remembered of the dream, the description by the dreamer of their recent waking life events and concerns before the dream, and the bringing together of these accounts of the dream and of waking life, so as to explore their connections. The Schredl dream group method (Schredl, 2007, 2011; Malinowski et al., 2014), also detailed below, aims to assist the dreamer in identifying common action and emotion patterns present in his or her dream and in his or her waking life. In both the Ullman and Schredl techniques, there is a phase in which the dream group can ask questions of the dreamer, in an attempt to consider connections between the content of the dream and the waking life experiences of the dreamer. In the Ullman technique, the focus is on the dreamer's recent waking life experiences over the days prior to the dream, whereas in the Schredl technique the dreamer can consider associations to experiences from any time in his or her life.

Control Conditions in Assessing Gains from Dream Interpretation

In their work on dream interpretation outcomes, Blagrove et al. (2010) and Edwards et al. (2013) did not have a control condition to which the dream condition would be compared. Those studies cannot, therefore, distinguish between outcomes specific to having a dream as the focus of the discussion, and outcomes due to the process of having a discussion irrespective of the initial text, if any, focussed on. In contrast, Hill et al. (2000) used a control condition of a description of a recent loss, finding that insights due to dream consideration were greater than due to loss consideration, and Hill et al. (1993) found greater insight from considering a dream than an event, although Diemer et al. (1996) found no difference between these. A further design used by Hill is the consideration by the dreamer of their own dream report, compared to the dreamer's spouse considering the same dream (Kolchakian and Hill, 2002). For the two studies reported here a control condition of the consideration of a recent event is used, the event report then being subject to either the Ullman technique or the Schredl technique. The hypothesis is that insight outcomes will be greater for the dream than for the event condition, because the dream content reflects the associative state of the brain during sleep and/or the functional reorganization changes in sleep, and specifically REM sleep, as reviewed above. The modified state of the brain during sleep would thus explain the bizarreness component of dreams and also the important representation of emotions and retrieval of components which can be temporally remote episodic memories not recently accessed in waking life (Grenier et al., 2005). It is thus plausible that dreams might be able to bring to consciousness, either explicitly or after free associations, material that is important but currently not being considered in waking life. Of course, that any empathic conversation could do this is also a possibility, and one that is tested for by the use of the event discussion control condition.

The theoretical justification for choosing this control condition is derived from the work of Pennebaker. Pennebaker (1997) describes how the process of writing for 15–30 min per day for 3–5 days about an important emotional issue results in subjective and objective physical and mental health benefits (Baikie and Wilhelm, 2005; Lu and Stanton, 2010; Shim et al., 2011). Pennebaker describes two explanations for this effect. The first is that disclosure through writing removes inhibition, which is assumed to have been a source of stress. The second explanation, which Pennebaker supports in his 1997 paper, is that the process of writing causes cognitive changes, resulting in the development of a more coherent story about life concerns. As a comparison to writing about an important emotional issue, Pennebaker (1997) used a control condition of writing about a superficial issue, which was found to result in lower benefits. So as to provide an appropriate comparison to the dream condition the recent event provided by each participant for the two studies here was thus requested to be personally significant.

Edwards et al. (2013) differentiate between "aha" experiences that occur when the participant realizes what waking life event is the source of part of the dream content, and "aha" experiences that occur when the consideration of dream content produces some realization about one's waking life, self, concerns, relationships, situations or actions. Both these types of aha experience contribute to the Exploration-Insight subscale on the GDI questionnaire. Edwards et al. (2013) show that Exploration-Insight is as high for the Ullman method as for the Hill method, which validates this dream group method, but did not differentiate in their results between these two types of insight. There is face validity to claiming that five items from the GDI Exploration-Insight and Action subscales refer to insight about oneself or one's life rather than insight about the source of dream contents. The aims to report separately the mean of these five GDI items, and the mean of the five Gains from Event Interpretation (GEI) items, that specifically address insight about the self, and Gains from Event Interpretation (GEI) items that specifically address insight about the self.

Although the Ullman technique was found by Edwards et al. (2013) to be an effective procedure for establishing connections between dream content and recent waking life experiences, waking life sources were found for only 14% of dream report text. This was achieved in sessions lasting approximately 1 h. One aim of the current study is to extend this work by assessing the extent to which waking life sources can be identified in Ullman sessions that instead last 45 min, and to assess this measure for the Schredl dream group method also, and for the control waking life texts.

Hypotheses

We hypothesize the following for the Ullman and Schredl studies:

(1) Participants will rate Exploration-Insight gains for the dream conditions as comparable to those obtained in the work of Hill, and specifically the meta-analysis results for that work as calculated by Edwards et al. (2013).

(2) Participants will rate Exploration-Insight gains more highly for the dream conditions than for the event conditions.

(3) Participants will rate the five questionnaire items that assess personal insight more highly for the dream conditions than for the event conditions.

Materials and Methods

Ullman Technique

Eleven participants (10 females, one male; ages 18–21, mean age = 20.18, SD = 0.98), all undergraduates at Swansea University, took part in this study. Each brought a written account of a recent dream and of a recent personally significant event to the group, which comprised the dreamer, and the authors CE and MB. The Ullman (1996) "Dream appreciation" method of detailing the content of the dream/event, detailing the recent waking life of the participant, and discussing or discovering connections between the report of the dream/event and prior waking life, was followed closely for the dream and the event texts.

The technique involves the following stages: 1A. Reading of the dream aloud by the dreamer. 1B. Clarification of the dream report by the group asking questions of the dreamer. 2A. Brief discussion of the dream by the group members other than the dreamer so as to imagine what feelings they would have experienced if the dream were their own, and then; 2B. Eliciting these individuals' projections about the dream in terms of their own lives so as to give symbolic or metaphorical meaning to the dream images. 3A. Response by the dreamer to stage 2. 3B.1 Description by the dreamer of his/her waking life context for the dream, in terms of the dreamer's life experiences, with particular emphasis on recent experiences and concerns. 3B.2 Reading the dream back to the dreamer, in the second person, so that any additional information about the dream or waking life can be obtained; and 3B.3 Orchestration, in which all members of the group suggest connections between information that the dreamer has given about their dream and information the dreamer has given about the dreamer's life. For a full description of the process, see Ullman (1996).

Schredl Technique

Nine participants (seven females, two males; ages 19–40, mean age = 27.11, SD = 9.09) took part in this study. Eight were current students at the University of Bedfordshire, one had completed postgraduate study. Each brought a written account of a recent dream and of a recent personally significant event to the group, which comprised the dreamer, author JM, and one of two research assistants. Schredl's (2011) "Listening to the dreamer (LTTD)" method of detailing the content of the dream/event, and discussing or discovering patterns of behavior or emotion that are in common between the dream/event report and prior waking life, was followed closely for the dream and the event texts.

The first five stages of Schredl's LTTD technique were used, as follows. 1. The dreamer shares a dream. The other group members ask questions with the aim of helping the dreamer to re-connect with the dream experience and to allow the dreamer to disclose more details about the dream. 2. The dream group ask the dreamer questions about whether they can make any associations between waking life memories and the dream. 3. The dreamer is asked to summarize the action pattern and emotion pattern of the dream. The actions and emotions are described in a very basic form at this point in the procedure. 4. The dreamer is asked to consider how the "Basic Action" and "Basic Emotion" patterns might link to sequences in waking life. 5. The dreamer is asked to consider whether he or she would like to alter any of their own thoughts or actions in the dream. (Schredl's LTTD technique does allow for consideration of future cognitive and behavioral changes as a result of the dream, but this sixth stage was not included in the use of the technique in this study.)

The Ullman study received ethics approval from the Research Ethics Committee of the Department of Psychology, Swansea University. The Schredl study received ethics approval from the Research Ethics Committee of the Department of Psychology, University of Bedfordshire. Participants gave written informed consent to take part after being given full information about what was involved in taking part. Information was given for consulting clinically qualified well-being services in the event of distress or discomfort as a result of reporting or discussing dreams or events, and it was made clear to participants throughout the study that they could halt their involvement, or halt discussion of any matter, at any point without needing to give explanation.

Measures

After the dream and event interpretation sessions participants completed the 14 item GDI questionnaire (Heaton et al., 1998b) and its counterpart the GEI questionnaire.

The GDI Exploration-Insight subscale comprises items on the experience of being in the group session, on insight obtained during the session about oneself or one's life, and insight about memory sources for the dream. Some items refer to more than one of these three categories. The GDI's Exploration-Insight subscale items are as follows (numbers refer to item number on the GDI questionnaire):

1. I was able to explore my dream thoroughly during the session.
2. I learned more about what this dream meant for me personally during the session.
6. I learned more from the session about how past events influence my present behaviour.
7. I learned more about issues in my waking life from working with the dream.
8. I felt like I was very involved in working with the dream during the session.
12. I learned things that I would not have thought of on my own.
13. I was able to make some connections, that I had not previously considered, between images in my dream and issues in my waking life.

The GEI questionnaire is an amended version of the GDI, with event substituted for dream throughout. For example, item 7, "I learned more about issues in my waking life from working with the dream" is changed to "I learned more about issues in my waking life from working with the event." The GDI and GEI questionnaires each have 14 items and use a 9-point scale for each item (1–9, where 1 = "strongly disagree" and 9 = "strongly agree"), which results in three subscales: Exploration-Insight gains, Experiential gains, and Action gains. Each of the subscales has a range of scores of 1–9.

The Action gains subscale of the GDI and GEI has five items, which refer to being able to change bad dreams (or change waking life events) and change waking life cognitions or actions, as a result of the session. Three items on the Action gains subscale refer to personal insight:

5. I got ideas during the session for how to change some aspect(s) of myself or my life.
10. I learned a new way of thinking about myself and my problems.
11. I will use the things that I learned in this dream [event] interpretation in my life.

One aim of this paper is to investigate the use of a personal insight subscale comprising items 5, 6, 7, 10, and 11.

The third subscale of the GDI/GEI, the Experiential gains subscale, has two items concerning re-experiencing the dream [event] and its emotions in the session.

Procedure

As there are cultural and historical expectations of hidden meanings and insight benefits from examining dreams (Morewedge and Norton, 2009), it is necessary to provide information to participants to justify examining an event. For the event condition justification a summary was given of the work of Pennebaker on the health and wellbeing benefits of constructing and examining one's own written narratives. On recruitment, and at the start of the session, participants were given two short written justifications about the usefulness of considering and discussing the content of a recent dream and of considering and discussing the content of a recent waking life event. Justifications were matched for length and included citations of the work of Hill for the dream condition and of Pennebaker for the event condition, citations in each case were to three academic papers and one book.

All participants took part in a dream and an event condition, each condition lasted approximately 45 min. The order of conditions was counterbalanced across participants. Each session was digitally voice recorded and later transcribed. The length of time of each session and the length of time spent on each stage of the Ullman and Schredl methods were calculated from the session transcripts so as to check whether the conditions differed on these variables. The emotional intensity and valance of the dream and event reports were rated by the participant so that any differences in these can be controlled for: a 1–7 hedonic scale was used where 1 = Very Pleasant, and 7 = Very Unpleasant. After the second of the two sessions for the Ullman study participants completed the GDI and GEI. For the Schredl study the GDI and GEI were completed at the end of their corresponding session.

The transcribed digital recordings of the sessions were used to produce an initial dream or event report, this being the report as stated in stage 1 of the Ullman and Schredl techniques. A canonical dream or event report was then produced, this being the initial dream or event report plus all additional or amended content of the report from the whole session. Two judges then assessed the transcripts of the dream and event conditions for both techniques so as to quantify the number of words of each canonical report for which prior waking life correspondences or sources were identified by the dreamer in the session. Inter-rater reliability for the number of words in the canonical report having, from the session transcript, a waking life source, were as follows: $\rho = 0.59$, $p = 0.006$ for dream reports and $\rho = 0.63$, $p = 0.003$ for event reports. The number of words that both judges agreed as having prior waking life correspondences identified by the dreamer in each session was then calculated. The percentage of words for each canonical report for which prior waking life correspondences or sources were identified was then also calculated.

Results

Ullman Study Results

The time spent on each stage are reported in **Table 1** and compared for dream versus event condition so as to ascertain whether the conditions were treated the same in terms of length of discussion. **Table 1** shows that the two conditions did not differ in time dedicated to each stage, except for stage 1, telling and clarifying the dream/event. **Table 1** also shows that the two conditions did not differ in report valence, that initial dream reports were significantly longer than initial event reports, and canonical dream reports were longer than canonical event reports, but not significantly so. Canonical reports were significantly longer than initial reports for dreams [$t(10) = 7.001$, $p < 0.001$] and events [$t(10) = 6.046$, $p < 0.001$]. Using independent judge scores of the transcripts, the mean number of words in the canonical dream and event reports identified by the dreamer, in the session, as connected to prior waking life, did not differ significantly between the dream and event conditions. Expressing this number of words as a percentage of the canonical report length, participants identified waking life sources for 19.42% of canonical dream report content and 22.52% of canonical event report content.

Table 2 shows that the dream condition was significantly higher than the event condition on the Exploration-Insight subscale, as hypothesized. Items 5, 6, 7, 10, and 11 of the GDI/GEI have a face validity of assessing level of Personal Insight obtained from the dream or event discussion. Pooling the GDI data from the current two studies and from Edwards et al. (2013), the five GDI items had a Cronbach's alpha = 0.778, and the corresponding five items on the GEI from the current two studies had a Cronbach's

TABLE 1 | Ullman method: valence and length in words of the initial dream or event report, time spent on each of the stages of the Ullman method, length of canonical report, and number of words in each canonical report connected, during the group session, to prior waking life, for the dream and event conditions.

	Dream *M* (SD)	Event *M* (SD)	*t*(10)	*P*
Valence	5.00 (1.34)	3.91 (1.92)	1.883	0.089
Length of initial report (number of words)	230.45 (63.56)	94.00 (38.07)	6.287	<0.001
Length of stage 1 (min)	11.05 (2.14)	8.41 (2.45)	2.636	0.025
Length of stage 2 (min)	5.77 (1.29)	5.41 (2.71)	0.398	0.699
Length of stage 3a (min)	0.77 (0.72)	0.91 (0.49)	−0.504	0.625
Length of stage 3b.1 (min)	17.91 (4.64)	13.86 (3.58)	2.01	0.073
Length of stage 3b.2 (min)	2.50 (0.71)	2.09 (0.58)	1.24	0.242
Length of stage 3b.3 (min)	6.73 (2.24)	5.95 (3.03)	0.866	0.407
Length of canonical report (number of words)	377.82 (121.46)	278.82 (115.05)	1.665	0.127
Number of words in canonical report connected to waking life	73.36 (17.31)	63.55 (25.91)	1.238	0.244

TABLE 2 | Gains from Dream Interpretation and Gains from Event Interpretation subscale scores for the Ullman dream and event conditions, mean of the personal insight items (5, 6, 7, 10, 11), and mean score for dream/event exploration item 1.

	Dream *M* (SD)	Event *M* (SD)	*t*(10)	*P*
Exploration-insight	7.82 (0.84)	7.21 (1.13)	3.59	0.005
Personal insight	6.60 (1.43)	6.20 (1.58)	2.29	0.045
Action	5.84 (1.38)	5.87 (1.65)	−0.15	0.882
Experiential	6.55 (1.37)	6.55 (1.62)	0.00	1.000
Item 1[a]	8.18 (1.25)	7.55 (1.92)	1.10	0.295

[a] *Item 1, "I was able to explore my dream/event thoroughly during the session."*

alpha = 0.893, indicating that the items can be taken together, and used as a measure of personal insight. **Table 2** presents the means of the five items for the dream and event conditions, showing that the dream condition resulted in significantly higher ratings for Personal Insight than did the event condition, as hypothesized. Scores on the Action subscale did not differ significantly between conditions. Scores on the Experiential subscale and on GDI/GEI item 1 show that the dream and event reports were explored equally thoroughly during the sessions.

The meta-analysis of the work of Clara Hill, calculated by Edwards et al. (2013), showed the following GDI subscale means: Exploration-Insight gains, mean = 7.40 (SD = 1.15); Experiential gains, mean = 7.03 (1.56); Action gains, mean = 6.51 (1.34). The GDI subscale means here do not differ significantly from the results of Hill for the three subscales [$t(10)$s = 1.66, −1.16, −1.61, for Exploration-Insight, Experiential, and Action subscales, respectively].

Schredl Study Results

The time spent on each stage are reported in **Table 3** and compared for dream versus event condition so as to ascertain whether the conditions were treated the same in terms of length of discussion. **Table 3** shows that the two conditions did not differ in time dedicated to each stage, except for stage 2, where the group ask the dreamer questions about whether they can make any associations between the dream or event and prior waking life memories. **Table 3** also shows that the two conditions did not differ in report valence, that initial dream reports were significantly longer than initial event reports, and canonical dream reports were longer than canonical event reports, but not significantly so. Canonical reports were significantly longer than initial reports for dreams [$t(8) = 4.599$, $p = 0.002$] and events [$t(8) = 4.729$, $p = 0.001$]. Using independent judge scores of the transcripts, the mean number of words in the canonical dream and event reports identified by the dreamer, in the session, as connected to prior waking life, did not differ significantly between the dream and event conditions. Expressing this number of words as a percentage of the canonical dream length, participants identified waking life sources for 17.26% of the text of canonical dream reports and 17.18% of the text of canonical event reports.

TABLE 3 | Schredl method: valence, and length in words of the initial dream or event report, time spent on each of the stages of the Schredl method, length of canonical report, and number of words in each canonical report connected, during the group session, to prior waking life, for the dream and event conditions.

	Dream *M* (SD)	Event *M* (SD)	*t*(8)	*P*
Valence	5.11 (1.83)	4.89 (2.32)	0.308	0.766
Length of initial report (number of words)	214.89 (105.58)	92.56 (41.16)	3.579	0.007
Length of stage 1 (min)	8.44 (2.95)	8.33 (2.80)	0.074	0.943
Length of stage 2 (min)	10.06 (4.44)	5.89 (2.19)	2.921	0.019
Length of stage 3 (min)	4.67 (1.48)	4.28 (2.90)	0.426	0.681
Length of stage 4 (min)	3.39 (1.93)	3.44 (3.02)	−0.084	0.935
Length of stage 5 (min)	1.56 (1.01)	1.50 (1.00)	0.109	0.916
Length of canonical report (number of words)	458.33 (173.38)	355.00 (184.97)	1.876	0.097
Number of words in report connected to waking life	79.11 (22.74)	61.00 (24.73)	1.950	0.087

TABLE 4 | Gains from Dream Interpretation and Gains from Event Interpretation subscale scores for the Schredl dream and event conditions, mean of the personal insight items (5, 6, 7, 10, 11), and mean score for dream/event exploration item 1.

	Dream *M* (SD)	Event *M* (SD)	*t*(8)	*P*
Exploration-insight	7.83 (1.09)	7.44 (1.56)	1.55	0.159
Personal insight	6.69 (1.63)	6.36 (1.86)	0.66	0.527
Action	6.62 (1.64)	6.53 (1.62)	0.25	0.809
Experiential	7.89 (1.58)	7.44 (1.63)	0.84	0.426
Item 1[a]	8.67 (1.00)	8.44 (1.13)	0.61	0.559

[a] *Item 1, "I was able to explore my dream/event thoroughly during the session."*

Table 4 shows that the dream condition was higher than the event condition on the Exploration-Insight subscale and on Personal Insight, but not significantly so. Scores on the Action subscale did not differ significantly between conditions. Scores on the Experiential subscale and on GDI/GEI item 1 show that the dream and event reports were explored equally thoroughly during the sessions.

The GDI subscale means here do not differ significantly from the results of Hill for the three subscales from the Edwards et al. (2013) meta-analysis [$t(8)$s = 1.18, 1.63, and 0.20, for Exploration-Insight, Experiential, and Action subscales respectively].

Discussion

In accordance with the first hypothesis, participants gave ratings on Exploration-Insight gains for the dream conditions that were comparable to those obtained in the work of Hill. Action and Experiential gains for the dream conditions were also comparable to those obtained in the work of Hill. Regarding the second hypothesis, the Ullman dream discussion condition resulted in significantly higher Exploration-Insight scores than did the event discussion control. In accordance with the third hypothesis, that Personal Insight would be greater after considering dreams than considering events, Personal Insight gains as assessed by five items taken from the Exploration-Insight and Action subscales were significantly higher in the Ullman dream than event condition. For the Schredl dream condition self-ratings for Exploration-Insight and Personal Insight were very close to the Ullman group ratings, but did not exceed significantly the ratings from the Schredl event condition. For both techniques the Experiential gains results show no significant difference between the dream and event conditions, hence the event discussions were engaged with, to the extent of re-experiencing feelings and reliving the event, as highly as for the dream discussions. Item 1 of the GDI/GEI similarly shows that dreams and events were explored equally thoroughly in the sessions. In general, time spent in each stage was the same for the dream and event conditions in each technique, showing that the conditions were treated equally in this regard.

Participants identified waking life sources for 19.4% of dream content in the Ullman sessions and 17.3% of dream content in the Schredl sessions; in comparison, in Edwards et al. (2013), 14% of dream report text was found to be directly related to recent waking life sources. The corresponding figures for text of recent event reports being connected in the sessions to prior waking life sources are 22.5 and 17.2% for the Ullman and Schredl techniques respectively. This indicates that the majority of text in dream reports, and waking life event reports, does not have obvious correspondences with prior waking life experiences, as least as can be identified in a 45 min discussion. Importantly, whereas the Ullman dream and event conditions differed significantly on Exploration-Insight and Personal Insight, they did not differ on the number of words of the dream or event report that were related by the dreamer to waking life during the sessions. The difference in insight outcomes between the conditions is thus not due to a confound of amount of waking-life relevant text in the reports. The results for the Schredl technique that there was no significant difference in eliciting personal insight for dream and event reports can be seen in terms of the Dodo effect, where there are equally high outcomes between different psychotherapeutic techniques and theories (Luborsky et al., 1975; Wampold et al., 1997). Indeed in practical terms it is not necessary for the dream condition to exceed the event condition in gains for benefits to be claimed for the group interpretation of dreams, even though theoretical reasons for a difference in outcomes between conditions can be proposed and hypotheses for this tested. The personal insight scores for event discussion in the two studies (means = 6.20 and 6.36 on a 1–9 scale) do indicate benefits to writing down and discussing an account of a recent significant event, and are thus supportive of Pennebaker's model of benefits of writing-based expression. However, it may be argued that higher scores could be obtained from other control conditions, with the relative advantage of the dream condition not then being so apparent. One possibility for a different control condition is the use of a recent daydream, to which the Ullman and Schredl techniques could then be applied. A method for the successful collection of daydream reports is described by Noreika et al. (2010), and used by them as a comparison condition for dream reports. As the daydream content is influenced by the current waking life concerns of the participant, this would be a suitable control condition in future studies. Furthermore, as REM sleep characteristics provide the theoretical basis for the hypothesis of greater insight following dream than event discussions, non-REM (NREM) dream reports could also be used as a control to which REM dream reports are compared.

The hypothesis that consideration of dream content might result in personal insight was supported by the premise that dreaming reflects emotional memory consolidation, functional reorganization and neural processes of insight occurring during sleep. However, it is not necessary to posit that dreams are related to a function of sleep for there to be a hypothesis of benefits in the consideration of dream content. It is possible that the sleeping brain state, for non-necessarily functional reasons, allows dream content to represent waking life matters about which we are more normally defended or even unaware when awake, because active inhibition of attending to these is suppressed during sleep (Freud, 1953; Wegner et al., 2004; Erdelyi, 2006; Bryant et al., 2011). To distinguish functional from non-functional accounts of dreaming would require investigations of the cognitive or other effects, if any, of unrecalled dreams, in addition to recalled dreams as in the current study: due to the difficulties involved such studies have as yet not been performed. Furthermore, Blagrove (2011) cautions that studies that do not experimentally alter dream content are insufficient to demonstrate that characteristics or effects of dream content are functional, as opposed to being solely reflective of pre-sleep emotions, cognitions and experiences (the latter view is argued by De Koninck et al., 2012), although possible higher level socio-cognitive characteristics of dream content, and possibly REM sleep processes (Blagrove et al., 2013) do need to be considered. In addition, we acknowledge also that there is the view, discussed in van Rijn et al. (2015), that declarative memory consolidation is primarily a function of Slow Wave Sleep rather than REM sleep (Diekelmann and Born, 2010; Lewis and Durrant, 2011). Such a view leads to the conclusion that the study of home dream content that is likely to be from REM sleep, as in the current study, might not have implications for the understanding of sleep-related functional memory processes, although studies referred to in the introduction of the current paper would counter this view. To investigate this further, the studies here should be repeated with REM and NREM dreams separately, with the hypothesis that there will be greater insight elicited from the former.

The two studies had various limitations. It may be that the types of insights elicited differ between the dream and event conditions, just as Hill et al. (2000) found that dream elicited insights tended to refer to personal relationships whereas consideration of loss insights tended to relate to the connection between past and present experience. Future work should address whether there are such qualitative differences. It may also be that full benefits from dream or event discussions do not occur for the brief timescale of discussion and assessment used in the current studies, and that further gains might occur with time. Furthermore, these lay group results might underestimate gains that could occur with more experienced researchers running the groups, or researchers with clinical experience, or participants with greater experience of considering their own dreams. It may also be that, as suggested by Heaton et al. (1998a), particular types of dreams, such as troubling or recurrent ones, are more important to explore, whereas the current studies used the most recent dream of each participant irrespective of content or type. Lastly, the sample sizes for the current studies were small, and, as most participants were female it is not clear whether these results would be generalizable to males, either because of differences between males and females in attitude toward dreams and dream interpretation (Schredl and Piel, 2008), or because of differences in dream content of males and females (Domhoff, 1996, 2003).

The extent to which the current results generalize to psychotherapy involving clients with a psychopathology needs also to be addressed and is dependent on several considerations. The first is the difference in dream content from that of controls that can result from particular psychopathologies. For example, in depression, compared to controls, themes of death (Firth et al., 1986; Schredl and Engelhardt, 2001), hostility and masochism (Hauri, 1976), and a lower number of characters (Barrett and Loeffler, 1992). In dissociative disorder, a high level of nightmares (Agargun et al., 2003). In schizophrenia, greater dream bizarreness (Noreika et al., 2010). In personality disorder, dreams with a lower number of interactions and higher emotionality than for controls (Guralnik et al., 1999). In terms of Pesant and Zadra's (2004) conceptualization that working with dreams in therapy can result in various benefits, such as client insights, increased involvement of the client in the therapeutic process, promoting a safe and trusting environment, facilitating access to issues that are central to the clients' lives, and a better understanding of clients' dynamics and clinical progress, benefits in some of these areas might be obtained for individuals with psychopathology. There is as yet, though, only a limited literature on this: Pesant and Zadra (2004) consider the extension of therapeutic consideration of dream content to psychopathological conditions, as also do Heaton et al. (1998a) in a case study on the analysis of recurrent and non-recurrent dreams of a client with dissociation. Secondly, a confounding factor here is the association of psychopathology with nightmares (Kales et al., 1980; Levin and Raulin, 1991; Berquier and Ashton, 1992; Levin, 1998; Chivers and Blagrove, 1999; Levin and Fireman, 2002) and with trait nightmare distress, which is the adverse reaction to having nightmares (Belicki, 1992; Claridge et al., 1997, 1998). Nightmares have been addressed in cognitive therapy, with the aim of reducing nightmare frequency using imagery rehearsal (Krakow et al., 2000; Lu et al., 2009; Ulmer et al., 2011), but not for any psychotherapeutic use of the nightmare content. As the studies here did not have nightmares reported, nor individuals reporting any psychopathology, the generalizability of the results to individuals with those characteristics requires further investigation. Furthermore, regarding client insight resulting from dream discussion, condition severity, which is inversely related to client insight toward a condition (Trevisi et al., 2012), might be a modulating variable for GDI.

Whereas the main aim of the current studies was to assess differences in gains between talking about a dream and talking about an event, it is important to recognize that some people might wish to talk about their dreams for reasons other than obtaining informational benefit from doing so. This point is reinforced by our findings that the benefit of considering dreams rather than events was significant but small in one study, and non-significant in the other. It is thus important to investigate the various reasons that people might wish to tell or discuss their dreams, which may be a function of the puzzling or emotional nature of the content. In this regard the finding by Hill et al. (2013) should be noted, that, although clients in psychotherapy who work with dreams do report that the dream work was helpful, session outcomes are not greater than for clients who do not discuss dreams in therapy. Of relevance are the findings of Olsen et al. (2013), who show a significant, positive correlation between dream sharing frequency in couples and perceived relationship intimacy, but with the benefit of dream sharing being primarily as entertainment. The study of insight benefits of dream sharing should thus be augmented by the study of the various motivations and consequences for sharing dreams, and individual differences in these.

To summarize, An impactful consequence of recalling dreams has been shown by Wright et al. (2014), who found that many recently bereaved persons experience vivid and deeply meaningful dreams of the deceased that may reflect and impact the process of mourning. Such dreams affect the bereavement process, including levels of comfort, sadness, and acceptance of the loved one's death. The authors conclude by emphasizing the importance for grief counselors of awareness of working with dreams. Our results support the view that benefits can be obtained by such consideration of dream content, in terms of identifying the waking life sources of dream content, and because personal insight gains may also occur. Mechanisms for this should now be investigated by the comparison of dream group outcomes for REM and NREM dreams separately.

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Dream-reality confusion in borderline personality disorder: a theoretical analysis

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This paper presents an analysis of dream-reality confusion (DRC) in relation to the characteristics of borderline personality disorder (BPD), based on research findings and theoretical considerations. It is hypothesized that people with BPD are more likely to experience DRC compared to people in non-clinical population. Several variables related to this hypothesis were identified through a theoretical analysis of the scientific literature. *Sleep disturbances*: problems with sleep are found in 15–95.5% of people with BPD (Hafizi, 2013), and unstable sleep and wake cycles, which occur in BPD (Fleischer et al., 2012), are linked to DRC. *Dissociation*: nearly two-thirds of people with BPD experience dissociative symptoms (Korzekwa and Pain, 2009) and dissociative symptoms are correlated with a fantasy proneness; both dissociative symptoms and fantasy proneness are related to DRC (Giesbrecht and Merckelbach, 2006). *Negative dream content*: People with BPD have nightmares more often than other people (Semiz et al., 2008); dreams that are more likely to be confused with reality tend to be more realistic and unpleasant, and are reflected in waking behavior (Rassin et al., 2001). *Cognitive disturbances:* Many BPD patients experience various cognitive disturbances, including problems with reality testing (Fiqueierdo, 2006; Mosquera et al., 2011), which can foster DRC. *Thin boundaries*: People with thin boundaries are more prone to DRC than people with thick boundaries, and people with BPD tend to have thin boundaries (Hartmann, 2011). The theoretical analysis on the basis of these findings suggests that people who suffer from BPD may be more susceptible to confusing dream content with actual waking events.

Keywords: dream-reality confusion, borderline personality disorder, sleep disturbances, dissociation, cognitive disturbances, dream content, boundaries

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Introduction

Dream-reality confusion (DRC) is a difficulty or inability to determine whether an event or experience occurred during the waking state or whether it was part of a dream. Although, only few studies on DRC in non-clinical populations have been conducted (e.g., Johnson et al., 1984; Mazzoni and Loftus, 1996; Rassin et al., 2001; Kemp et al., 2003), DRC has been investigated in specific groups, including narcolepsy patients (Wamsley et al., 2014). Research has found that there is a relationship between DRC and psychotic symptoms (e.g., Hempel et al., 2003), but the authors of the present paper have not been able to find any scientific studies on the relationship between DRC and borderline personality disorder (BPD).

BPD is *a pervasive pattern of instability of interpersonal relationships, self-image and affect, and marked impulsivity that begins by early adulthood and is present in a variety of contexts* (DSM-V; American Psychiatric Association, 2013, p. 663). To qualify for this diagnosis, the person should, among other symptoms, make a frantic effort to avoid real or imaginary abandonment, experience a chronic feeling of emptiness or stress-related temporary paranoid symptoms, or exhibit severe dissociative symptoms. Moreover, persons with BPD often engage in self-destructive behaviors and are at significant risk of suicide. Borderline personality disorder affects between 1 and 5.9% of the general population (Torgersen et al., 2001; Aragonés et al., 2011).

Due to the complex psychopathology of BPD, numerous studies have examined different areas of functioning in individuals with this disorder. The present theoretical analysis addresses the question of whether individuals with certain features of BPD may have difficulty distinguishing between dreams and reality.

The aim of this paper is to provide an overview of the current knowledge of DRC in relation to features of BPD. We hypothesize that BPD subjects are highly predisposed to experience DRC. This hypothesis is supported by the underlying assumption that there are groups of interrelated variables that are present in both DRC and BPD. These variables, which we identified through an analysis of the scientific literature, can be divided into the following categories: (i) sleep disturbances; (ii) dissociative symptoms; (iii) negative dream content; (iv) cognitive disturbances; and (v) thin boundaries. This division was made on the basis of theoretical considerations; no factor analyzes have been conducted yet. Each of these five variables is presented separately below.

Variables Present in BPD and DRC

Sleep Disturbances

Sleep disturbances, for the purpose of this theoretical analysis, include a variety of problems with sleep that are discussed below. Such sleep problems are very common among individuals with BPD (Hafizi, 2013). Though there is little epidemiological data on sleep disorders among persons diagnosed with BPD, cross-sectional studies show that sleep disorders are prevalent in 15–95.5% of this group (e.g., Asaad et al., 2002; Semiz et al., 2008; Plante et al., 2009; Sansone et al., 2010).

Compared to a non-clinical group, individuals with BPD take more time to fall asleep, sleep for shorter times, have lower sleep efficiency, and have frequent sleep disturbances (Semiz et al., 2008). EEG recordings showed, for example, that study participants in a BPD group, compared to a non-clinical population, had shorter NREM sleep stages 2 and 4 and longer NREM sleep stage 1, and had high-voltage delta waves during NREM sleep (Benson et al., 1990; Philipsen et al., 2005). REM sleep also was different between the groups, with BPD patients spending more time in REM sleep, which had a longer latency, a longer first episode, and a higher REM density, as well as high-voltage delta and theta waves in REM sleep, in participants with BPD (Asaad et al., 2002; Philipsen et al., 2005). Patients with BPD also have more night awakenings than persons from a non-clinical population (Battaglia et al., 1993; La Fuente et al., 2001). Frequent awakenings may lead to difficulty determining whether an event/experience occurred during the waking state or was part of dream content (Trajanovic et al., 2007).

Labile sleep–wake cycles are another example of sleep disturbances. They may occur in the course of BPD and they are correlated with DRC (Fleischer et al., 2012). Labile sleep–wake cycles may promote the intrusion of dreamlike experiences into waking consciousness that can lead to DRC and foster the feeling of depersonalization, which is a dissociative symptom. They also have an adverse effect on memory, thus favoring the creation of false memories (van der Kloet et al., 2012). Individuals who report sleep disturbances score high on dissociative scales, fantasy proneness (a tendency for *deep and long-standing involvement in fantasy and imagination;* Lynn and Rhue, 1988, p. 35) and are prone to false memories (Giesbrecht and Merckelbach, 2006).

Taken together, the above relationships appear to support our hypothesis that BPD patients are likely to experience DRC. It is suggested that a wide range of sleep disturbances, such as labile sleep–wake cycles, increase the tendency to experience night awakenings or nightmares (which are discussed in Section "Negative dream content") in patients with BPD, which increases the probability that such persons will have problems distinguishing whether an event/experience occurred during the waking state or was part of dream content.

Dissociative Symptoms

Dissociation describes a state of disruption and/or discontinuity in integrated psychological functioning, such as consciousness, memory, identity, or perception (DSM-V; American Psychiatric Association, 2013). Dissociative symptoms include, derealization – the impression that the surrounding world or reality have changed, depersonalization – feeling as though one is an outside observer of one's own self, and amnesia – an inability to remember, store, and/or evoke memories.

Dissociative states are experienced by approximately 2/3 of patients with BPD (Korzekwa and Pain, 2009). Persons diagnosed with BPD have a stronger tendency toward dissociative symptoms than non-clinical population and individuals who suffer from depression or schizophrenia (Merckelbach et al., 2005). The occurrence of dissociative symptoms during the course of BPD may be associated with childhood traumatic events. According to one of the theories of the etiology of BPD, this personality disorder develops in individuals who report that traumatic events were a characteristic of their early lives, mainly physical abuse and emotional neglect. A study of 139 patients with BPD found that those who had high scores on the *Dissociative Experience Scale* (DES), which measures the frequency of dissociative symptoms, such as autobiographical amnesia, derealization, depersonalization, absorption, and identity alteration (Bernstein and Putnam, 1986), experienced significantly more severe emotional and physical neglect and emotional and physical abuse (but not sexual abuse) during childhood than those who had low scores on the DES (Watson et al., 2006). The results suggest that individuals exposed to severe traumatic events during childhood are more likely to develop dissociative symptoms. Traumatic experiences may contribute to the development of dissociative symptoms because trauma-related stress leads to a sudden discontinuity of the individual's experience, as it arouses fear about security and disturbs the connection between the inner and outer environment. Traumatic experiences also often interfere with the integration of mental functions, thus, leading to their dysfunction (Vermetten and Spiegel, 2014). Moreover, dissociative symptoms involve automatic avoidance strategies that defend consciousness from traumatic memories (Briere, 2002).

It is noteworthy that dissociative symptoms are one of the correlates of DRC (Rassin et al., 2001). Levitan (1967, p. 157) noted that *derealization is a compromise between dreaming and waking*. It seems that frequent experiences of dissociative symptoms or their intensification may produce frequent intrusions of dreams into experiences during the waking state.

Dissociative symptoms and proneness to fantasy – characteristics linked to DRC – are correlated, and it appears this correlation can be mediated by experiences during sleep (Giesbrecht and Merckelbach, 2006). High fantasy-prone students report more dissociative symptoms than their friends who score low or medium on fantasy-proneness (Rauschenberger and Lynn, 1995; Waldo and Merritt, 2000). Furthermore, individuals who find it difficult to discriminate between dreams and reality score higher on scales that measure dissociative symptoms and fantasy proneness than individuals who do not confuse dream content with experiences during the waking state (Rassin et al., 2001). A study of 51 women from the general population found that fantasy proneness is linked to both dissociative symptoms and everyday cognitive failures (Merckelbach et al., 1999). Moreover, dissociative symptoms, fantasy proneness, cognitive failures, and sleep disturbances are correlated (van Heugten – van der Kloet et al., 2014a). Later in the current paper, we present data indicating that disturbances in cognitive functioning are among the variables that increase proneness to DRC.

The relationship between dissociative symptoms and fantasy proneness also has been observed in clinical populations. Merckelbach et al. (2005) demonstrated such relationships in groups of subjects diagnosed with BPD, schizophrenia, and major depressive disorder . In addition, Steiger et al. (2000) found that dissociative symptoms were related to impulsivity in persons with BPD. This association is interesting because impulsivity is one of the diagnostic features of BPD (DSM-V, American Psychiatric Association, 2013).

To summarize, the above findings support our hypothesis that individuals with diagnosed BPD are more likely to experience DRC because of their tendency to experience dissociative symptoms and related phenomena, such as fantasy proneness, sleep disturbances, and cognitive problems.

Negative Dream Content

Individuals suffering from BPD experience more negative life events than other individuals – even those with other personality disorders (Pagano et al., 2004). According to the classical continuity hypothesis (Hall and Nordby, 1972; Schredl, 2003), dreaming reflects the dreamer's waking life experience, therefore, the dream content of patients with BPD may be more negative that the dream content of other people. The quantitative analysis of a group of 27 individuals diagnosed with BPD and a non-clinical group of 20 individuals showed that the BPD group had dreams with more negative affect than those in the non-clinical group. Generally, individuals suffering from BPD experience negative dreams, including nightmares, more often than individuals who do not have any of the characteristic symptoms of this personality disorder (Schredl et al., 2012).

Nightmares are sleep disturbances that are related to sleep disorders. They are defined as vivid dreams, charged with negative emotions that awaken the dreamer from sleep (DSM-V; American Psychiatric Association, 2013). About 49% of patients with BPD are troubled by nightmares, whereas the prevalence of nightmares in the non-clinical population is estimated to be about 4–10% (Levin and Nielsen, 2007; Simor et al., 2010). The higher frequency of nightmares among BPD patients compared to the non-clinical population is related to greater emotional instability and heightened neuroticism in this clinical group (Simor et al., 2010). The intensity of BPD symptoms is positively correlated with the frequency of nightmares (Semiz et al., 2008). To try to explain the prevalence of nightmares in persons with BPD, we present two theories: a nightmare model proposed by Levin and Nielsen (2007), and the Emotional Cascade Model developed by Selby et al. (2013).

Levin and Nielsen (2007) proposed a theory to explain the occurrence of dysphoric dreaming, which is based on two major assumptions: *cross-state continuity* and *multilevel explanation*. The first, *cross-state continuity*, assumes that *some structures and processes implicated in nightmare production are also engaged during the expression of pathological signs and symptoms such as dissociative symptoms during the waking state* (Levin and Nielsen, 2007, p. 495). The second, the *multilevel explanation*, refers to the idea that nightmare formation can be explained at two different levels: the cognitive–emotional level and the neuronal level. At the cognitive–emotional level, there are imagery processes that represent emotional dream imagery, whereas the neuronal level contains a network of brain regions responsible for imagistic and emotional processes. This model was created to explain the occurrence of nightmares in the course of posttraumatic stress disorder (PTSD); however, it may also be used in an attempt to describe experiences related both to nightmares and cross-state continuity in patients diagnosed with BPD. We will not discuss the concept of neuronal correlates of DRC and BPD, as this is beyond the scope of the present article. Instead, we will focus on the notion of *cross-state continuity* with reference to BPD. In their model, Levin and Nielsen (2007) consider a number of factors that underlie *cross-state continuity*, such as affect load – *a state factor is the combined influence of stressful and emotionally negative events on an individual's capacity to effectively regulate emotions* (p. 497), and affect distress – *a trait factor is a long-standing, dispositional tendency to experience heightened distress and negative affect, and to react with extreme behavioral expressions* (p. 498). Other factors include high degrees of physiological and psychological reactivity, maladaptive coping, fantasy proneness, imagery vividness, and thin boundaries. Numerous studies suggest that almost all of these factors are usually present during the course of BPD, however more recent studies indicate that there is no heightened physiological reactivity in BPD (e.g., Linehan, 1993; Merckelbach et al., 2005; Hunt, 2007; Kuo and Linehan, 2009; Hartmann, 2011; Mosquera et al., 2011; Cavazzi and Becerra, 2014). Persons diagnosed with this personality disorder are characterized by emotional dysregulation, which is the inability to flexibly respond to and manage emotions, entailing emotional sensitivity, heightened and labile negative affect, a deficit of appropriate regulation strategies, and a surplus of maladaptive regulation strategies (Carpenter and Trull, 2013). In addition, BPD entails affective instability and a low level of emotion recognition (Cole et al., 2009).

According to Linehan's (1993) biosocial theory, which explains the etiology of BPD, this personality disorder develops in children (i) who have a biological propensity to experience negative affect, and (ii) who are in an invalidating and toxic social environment. In BPD, the biological sensitivity to emotional stimuli, heightened negative affect, and a slow return to emotional baseline are connected with difficulty in discriminating and labeling one's own emotional states, initiating adequate coping strategies to manage these emotional states, and being able to reduce intense negative affective states. Studies confirm that BPD patients display a negative distortion in the identification of their own emotional states and the emotional states of other persons (e.g., Morey, 2014). The inability to accurately recognize emotional states may intensify negative affect, emotional instability, and emotional reactivity in everyday life. Furthermore, patients with BPD are unable to tolerate distress and they usually use maladaptive regulation strategies to cope with distress and the negative emotions they experience, such as ruminations, impulsive behaviors, or cognitive avoidance (Carpenter and Trull, 2013). Disorders of emotional processes in patients with BPD seem to occur not only in the waking state, but also during dreaming, as in the case of nightmares (Simor et al., 2010). We hypothesize that waking and dreaming states may involve similar experiences; therefore, persons with BPD may have difficulty discriminating whether an event/experience occurred during the waking state or was part of dream content.

Emotional dysregulation, which is one of the factors associated with nightmares in Levin and Nielsen's (2007) theory, is also mentioned by Selby et al. (2013) in their Emotional Cascade Model (ECM). The ECM attempts to explain the etiology of bad dreams experienced in the course of BPD. The effects of nightmares and other bad dreams, apart from the fear they produce, can involve deficits in appropriate emotion-regulation skills, and decrease ability to cope with distress during the subsequent day, according to the ECM. Patients with BPD experience emotional cascades during the waking state, and this negative affect induces rumination – repetitive thoughts with mainly negative content. Ruminations increase negative affect, which, in turn, intensify ruminations. These processes result in increased cognitive activity during sleep that favors the appearance of nightmares and maladaptive behaviors during the waking state that are intended to cope with negative emotions. It seems that frequent nightmares in persons with BPD may influence the occurrence of negative life events (Selby et al., 2013). Generally, a simplified model of emotional cascades assumes the subsequent occurrence of: negative emotional experiences during wakefulness ⟶ increase in ruminations ⟶ escalation of negative emotions ⟶ increase in ruminations ⟶ a very aversive emotional state ⟶ / possible dysfunctional coping skills connected with affect regulation (e.g., self-harm, substance use) / ⟶ elevated cognitive activity during sleep connected with emotional cascades during the waking state ⟶ nightmares that are sleeping emotional cascades ⟶ nightmares may increase negative affect and vulnerability to stressors during wakefulness ⟶ negative emotional experiences during wakefulness... (for a detailed description, see Selby et al., 2013).

Elevated cognitive arousal during sleep may cause awakenings or semi-awakenings, which consequently may lead to difficulty distinguishing between dreaming and waking experiences (Trajanovic et al., 2007; Selby et al., 2013). In addition, the inability to cope effectively with stressful situations may enhance the tendency toward dissociative states (Mosquera et al., 2011), which finally may result in an increased proneness to DRC.

Moreover, a study by Rassin et al. (2001) demonstrated that dreams that are more likely to be confused with reality are realistic, permeated with negative affect, and give rise to behavior in the waking state. Yet, because BPD patients have more negative experiences in both the waking state and sleeping state and more cognitive disturbances, they may have more difficulty recognizing whether an event/experience occurred during the waking state or was part of a dream. Taken together, the findings suggest that frequent unpleasant dream content in BPD may be a factor that increases proneness to DRC.

Cognitive Disturbances

Patients with BPD can experience a number of different cognitive disturbances. These include problems with metacognitive monitoring, which refers to the ability to observe one's own thinking processes, as well to detect errors in one's own reasoning, and inconsistencies in one's own narrations. Metacognitive monitoring refers to "thinking about thinking." Metacognitive knowledge, which is the ability to notice that some things/events may not be as they appear to be, is also distorted in BPD (Sharma and Singh, 2012). Usually, executive functions, such as working memory and response inhibition, also are disturbed in BPD (Hagenhoff et al., 2013). Moreover, BPD is characterized by deficits in feedback processing, altered social inference, and poor decision-making skills (Trivedi, 2006; Mak and Lam, 2013). Generally, four types of cognitive disturbances are distinguished in BPD: (i) transient, quasi-psychotic cognition, (ii) dissociation, (iii) social cognitive biases, and (iv) neurocognition (Fertuck and Stanley, 2006). A detailed description of cognitive problems in BPD, however, remains beyond the scope of the present paper.

What is important is that problems with reality testing may occur in patients with BPD (Fiqueierdo, 2006). Reality monitoring, which is related to reality testing, seems to play a significant role in the process of distinguishing dream content from waking experiences. Reality monitoring, a type of source monitoring, is defined as the ability to discriminate between memories of actual events, and memories of dreamed events, imagination, or delusions. Reality monitoring consists of two decision-making processes: (i) evaluation of whether the characteristics of a memory trace are more typical of memories of external events or memories generated internally; and (ii) evaluation based on present memory/knowledge, which is a more complex process and takes more time. Memory source is distinguished on the basis of its characteristics: memories of actual events include more perceptual and contextual details, whereas memories of consciously imagined events include traces of cognitive operations that were involved in their creation. Dreams are classified as internally generated events, which are difficult to distinguish from similar, external events because they are created without conscious cognitive operations (Johnson et al., 1984). In the case of dreams, conscious cognition, which is the most important cue that would help differentiate between internally generated memories and those generated externally is not present. These conclusions indicate that DRC may be associated with difficulty with reality monitoring.

The temporary suspension of the source monitoring process, along with reduced ability to respond to a sensory stimulus and reduced attention, is one of the common features of both dreaming and waking fantasy. These processes may make it more difficult to distinguish between the content generated during dreaming and waking fantasy. Both waking fantasy and dreams play an integral role in mood regulation, adaptive information processing, and maintenance of self-cohesion by providing working templates for future goal-directed behavior and the development and maintenance of self-schemas (Levin and Young, 2002). BPD patients exhibit certain cognitive disturbances that make them more prone to problems related to reality testing, and waking fantasy may also disturb the processes involved in correct source monitoring. Furthermore, it seems that mood regulation is disturbed in BPD because of more negative dream content and emotional cascades at night (Selby et al., 2013). Cognitive and emotional processes during dreaming and wakefulness interact, and their interaction may contribute to difficulty in distinguishing whether an event/experience occurred during the waking state or in a dream.

Moreover, individuals who are more likely to make cognitive mistakes are less likely to trust their cognitive skills (van Heugten – van der Kloet et al., 2014a); thus, they may be more responsive to suggestions from other people. We hypothesize that people with BPD who have some cognitive deficits will trust their cognitive processes less because they are not sure if their perception of reality is correct. Our assumption is that due to their cognitive disturbances, persons with BPD, compared to non-clinical populations, more often will be unsure what the source of certain events or experiences are (dream vs. reality), and may even make incorrect judgments about their source. The difficulty that BPD patients encounter in reality testing (Fiqueierdo, 2006) and their problems with metacognitive monitoring and metacognitive knowledge (Sharma and Singh, 2012) seem to be the only examples of cognitive disturbances that could lead to a higher probability of experiencing DRC, compared to people from non-clinical populations.

Thin Boundaries

The concept of boundaries, which was defined by Hartmann (2011), refers to a wide spectrum of boundaries in the mind, including interpersonal boundaries (the self vs. others), boundaries between the self and the outside world, and boundaries between different states of consciousness (e.g., the waking state or dreaming state). Thus, boundaries refer to: (i) connectedness among various aspects of the mind (i.e., the relationships among thoughts, emotions, and memory), including relationships among the personal past, future, and present; and (ii) connectedness between the self and the outside world (Hartmann, 2011). People have been characterized as having thin or thick boundaries (Hartmann et al., 1991; Hartmann, 2011). As boundaries are generally stable across situations, there is a high probability that individuals with thin boundaries in certain areas will have thin boundaries in other areas (Hartmann, 2011).

Patients with BPD tend to have thin boundaries (Hartmann, 2011), and individuals with thin boundaries have higher dream recall than those with thick boundaries. They also experience more emotions in their dreams, have dreams that are more negative and emotionally intense, dream more frequently about verbal interactions with others, and regard their dreams as more meaningful and creative (Schredl et al., 1999). A higher dream recall and other vivid night experiences are associated with a greater tendency for absorption, which is *a state of heightened imaginative involvement in which an individual's attention capacities are focused in the behavioral domain, often to the exclusion of explicit information-processing in other domains and fantasizing* (Levin and Young, 2002, p. 203). Levin and Young (2002) demonstrated that absorption is correlated with heightened creativity, a tendency toward dissociation, and increased involvement in imagination-based activities, with concomitant alterations in consciousness (Levin and Young, 2002). In this context, it may be interesting to raise questions as to whether a greater ability to recall dreams increases the probability that dream content will be confused with real events. As BPD patients have a greater tendency for absorption (Zanarini et al., 2000), they would experience DRC more frequently, perhaps in connection with other variables discussed in this paper.

Thin boundaries seem to enhance the intrusion of dreamlike content into consciousness in the waking state, which may lead to difficulty distinguishing whether an event/experience occurred during the waking state or in a dream (Hartmann, 2011). Additionally, these intrusions may favor the occurrence of dissociative symptoms, which as mentioned above, are correlated with DRC (Rassin et al., 2001; van Heugten – van der Kloet et al., 2014a). Taken together, these data suggest that individuals with thin boundaries may be more prone to DRC. Thus, it is possible that patients diagnosed with BPD also may be more prone to DRC. Given the above considerations, it would be interesting to conduct studies on the relationship between creativity and DRC in BPD populations and non-clinical populations. Although a recent study by van Heugten – van der Kloet et al. (2015) found a moderate correlation between state dissociation and creativity, no significant correlation was found between creativity and unusual sleep experiences. Future studies should include DRC as a construct to elucidate its relationship with creativity.

Conclusions

The variables that may lead to an increased tendency to experience DRC in patients with BPD were described in the preceding paragraphs. Taking everything into account, we propose a tentative model that patients with BPD are more prone than non-clinical population to experience difficulty or an inability to determine whether an event/experience occurred during the waking state or was part of a dream.

Patients with diagnosed BPD may be more prone to experience dissociative symptoms because of traumatic events in their early childhood (Watson et al., 2006), and dissociative symptoms are correlates of DRC (Rassin et al., 2001). Thus, the greater tendency toward dissociative symptoms among persons with BPD may make them uncertain whether something they remember happened in their dreams or while they were awake. Dissociative symptoms are correlated with fantasy proneness, which is also correlated with DRC (Rassin et al., 2001; Merckelbach et al., 2005; Giesbrecht and Merckelbach, 2006). Furthermore, persons with BPD often suffer from various sleep disorders (Hafizi, 2013), and sleep disorders (for instance, nightmares) and unusual sleep experiences are related to dissociative symptoms and to DRC (Giesbrecht and Merckelbach, 2006; van Heugten – van der Kloet et al., 2014b). Moreover, patients with BPD experience negative emotions during wakefulness that are related to negative emotional experiences during dreaming (Selby et al., 2013). This process may also be connected to elevated cognitive arousal during sleeping that causes awakenings or semi-awakenings, which consequently lead to difficulty distinguishing between dreaming and waking experiences (Trajanovic et al., 2007; Selby et al., 2013). In addition, dreams that are more likely to be confused with reality are realistic, evoke negative emotions, and give rise to behavior in the waking state (Rassin et al., 2001). The dream content of patients with BPD is more negative than the dream content of individuals in non-clinical populations, and people with BPD tend to experience a number of different cognitive disturbances, such as problems with reality testing, metacognitive deficits, altered social inference, poor decision-making skills, or cognitive distortions (Fiqueierdo, 2006; Trivedi, 2006; Wenzel et al., 2006; Schredl et al., 2012; Sharma and Singh, 2012; Mak and Lam, 2013). We hypothesize that due to the feedback loop of negative affect during dreaming and wakefulness, cognitive disturbances, and increased impulsivity, patients with BPD may take actions after awakening that are based on their dream content, because they are convinced that these events happened in reality. Moreover, people with BPD are characterized by thin boundaries (Hartmann, 2011), which may further enhance the confusion between dreams and wakefulness.

This theoretical analysis, including such variables as sleep disturbances, dissociative symptoms, negative dream content, cognitive dysfunction, and thin boundaries leads to the proposition that patients with BPD may be more prone to DRC, compared to non-clinical population. Future research on the general working model should involve the use of factor analysis and structural equation modeling in order to identify and confirm important variables and explore the complex relationships among these variables.

We plan to conduct empirical verification of these relationships. The aim of this extensive research program is not only to examine whether patients with BPD are more vulnerable than other people to experience DRC, but to study comprehensively the psychological and neuropsychological aspects of sleep and dreams, using subjective and objective methods, on a continuum: BPD – some features of BPD – lack of BPD.

The theoretical analysis presented above is exploratory in nature and is intended to serve as a starting point for further, more advanced analyses, and to provide a theoretical basis for planning empirical studies.

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Imagining the impossible before breakfast: the relation between creativity, dissociation, and sleep

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Dissociative symptoms have been related to higher rapid eye movement sleep density, a sleep phase during which hyperassociativity may occur. This may enhance artistic creativity during the day. To test this hypothesis, we conducted a creative photo contest to explore the relation between dissociation, sleep, and creativity. During the contest, participants ($N = 72$) took one photo per day for five consecutive days, based on specific daily themes (consisting of single words) and the instruction to take as creative a photo as possible each day. Furthermore, they completed daily measures of state dissociation and a short sleep diary. The photos and their captions were ranked by two professional photographers and two clinical psychologists based on creativity, originality, bizarreness, and quality. We expected that dissociative people would rank higher in the contest compared with low-dissociative participants, and that the most original photos would be taken on days when the participants scored highest on acute dissociation. We found that acute dissociation predicted a higher ranking on creativity. Poorer sleep quality and fewer hours of sleep predicted more bizarreness in the photos and captions. None of the trait measures could predict creativity. In sum, acute dissociation related to enhanced creativity. These findings contribute to our understanding of dissociative symptomatology.

Keywords: dissociation, creativity, dreaming, photography, hyperassociativity

Introduction

Dissociative symptoms are notorious for their enigmatic nature and include phenomena that encompass excessive daydreaming, memory problems, severe absentmindedness, and impairments, and discontinuities in perceptions of the self, identity, and the environment (Bernstein and Putnam, 1986). Mild dissociative symptoms, related to absorption, and occasional experiences of depersonalization, are not uncommon in the general population, but relatively rare disorders such as dissociative identity disorder and dissociative amnesia represent severe manifestations of psychopathology (Lynn et al., 2012).

Recent studies have linked dissociative symptoms to vivid dreaming, nightmares, and other unusual sleep experiences (Van der Kloet et al., 2012; Van Heugten–Van der Kloet et al., 2013, 2014). However, the famous 19th century British neurologist Hughlings Jackson was the first to view dissociation as the uncoupling of normal consciousness, which results in what he termed ’the dreamy state’ (Meares, 1999). Interestingly, a century later, Levitan (1967, p. 157) hypothesized that “depersonalization is a compromise state between dreaming and waking.”

Previous research has addressed the connection between dissociative symptoms and sleep disturbances. For example, in a recent study (Van Der Kloet et al., 2013), we assayed dissociative symptoms and EEG sleep parameters and found that lengthening of rapid eye movement (REM) sleep predicts dissociative symptoms. Germane to this finding is the idea that the progression of waking state to REM sleep is marked by an increase in “fluid” and hyperassociative thinking (Stickgold et al., 2001), which is a type of mentation also observed in certain dissociative individuals (Van Heugten–Van der Kloet et al., 2013; Lynn et al., 2014).

Rapid eye movement sleep is marked by an increase in cholinergic transmission, similar to wakefulness. At the same time, noradrenergic firing is inhibited during REM sleep, whereas all modulatory neurons slow down but keep firing during non-REM sleep. Accordingly, REM sleep appears to be an ideal state for hyperassociative connections to be made during dreaming. Waking consciousness involves many types of cognitions, such as daydreaming and mind wandering, which in excess could be considered dissociative in nature, (e.g., Foulkes and Fleisher, 1975). Domhoff (2011) describes these cognitions as the ‘default network’ of waking cognition (i.e., mental activity when we are not focusing our thoughts). Hartmann (2010) and Montangero (2012) have argued that thought across the sleep–wake cycle should be regarded as a continuum, with typical dreaming on the one end, focused waking thought on the other end, and daydreaming and mind wandering in between (see **Figure 1**). Indeed, Solms (1999) argued that “Mental state is a constantly negotiated compromise between the poles of waking (. . .) and dreaming.”

Waking and dreaming consciousness could be viewed as a continuum with experiences such as dissociation and lucid dreaming conceptualized in the middle range. Kahan and LaBerge (1996, 2011) and Kahan et al. (1997) have shown that while there is a reduction in volition in dreaming compared to waking cognition, other properties of thought such as reflective awareness are no more present in waking thought than dreaming. Thus, waking consciousness is capable of the associative thinking thought to be typical of dreaming, and dreaming is capable of the directed and reflexive thinking thought to be typical of waking cognition. We suggest that sleep disturbance could ‘push’ waking consiousness more toward the ‘dreaming’ end of the continuum, fostering less linear, and highly associative thinking during waking (see **Figure 1**). Indeed, loosening of associations and lack of insight are considered to be key elements of schizophrenia (Bleuler et al., 1911/1950; Carroll et al., 1999). This fits well with Hobson’s (2002) view of differentation between waking and dreaming as “a constantly negotiated compromise” (Hobson, 2002, p. 102).

Llewellyn (2011) has advanced an intriguing theory which posits that a progressive de-differentation of wake and dream states of consciousness eventually results in schizophrenia. Because of the differences in neuromodulatory systems between waking and dreaming, the self and the world during dreaming appear to differ from during waking. The perceived world during waking depends on making sense of external sensory input, which engenders a strong sense of external reality in which the ‘self and its inner-world’ exists. In contrast, the world during dreaming makes less distinction between subjectivity and objectivity. A self-organizing system allows for the self and the world in both states to be integrated. Accordingly, when a degree of loss of this self-organization occurs, de-differentation of the waking and dreaming states may ensue, fostering a perception of loss of self, as occurs during episodes of depersonalization.

Creativity involves the understanding of novel ideas and relations; originality and flexibility are two key features of creativity. Chakravarty (2010) suggests that for creativity to occur, we

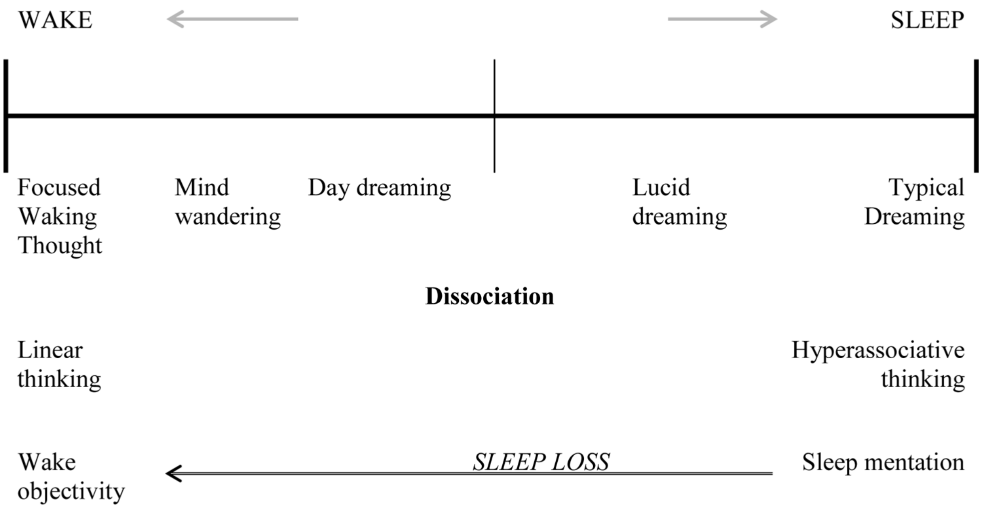

FIGURE 1 | Consciousness across the sleep-wake cycle depicted as a continuum. Sleep loss or sleep disturbances may ‘push’ sleep mentation more toward the waking end of the continuum, fostering less linear thinking and the perception of a loss of self during wake, setting the stage for dissociative symptoms.

need to be able to engage in divergent thinking, novelty seeking behavior, and suppress latent inhibition to some extent. Most importantly, a creative brain is highly interconnected (both inter- and intrahemispherically), with divergent thinking promoting more connections to be forged through development of new synapses. Relatedly, Faust-Socher et al. (2014) found enhanced creative thinking under dopaminergic therapy in patients with Parkinson's disease. They proposed that dopamine reduced latent inhibition, thereby enhancing creativity by loosening the associative networks (Faust-Socher et al., 2014). Furthermore, Walker et al. (2002) observed that subjects who were awakened from REM sleep displayed more cognitive flexibility (a 32% advantage), as measured by the number of anagram puzzles solved, than those awakened from NREM sleep.

Rapid eye movement sleep may pose as an ideal state to facilitate creative thinking, with mild frontal dysfunction and high interconnectness through associative networks. We suggest that in highly dissociative people who experience more vivid dreams and other unusual sleep experiences (Van der Kloet et al., 2012), associative and less linear thinking could occur more frequently during waking consciousness, facilitating the emergence of creativity during waking consciousness. Moreover, our research indicates that dissociative symptoms are closely related to fantasy proneness (Rauschenberg and Lynn, 1995; Merckelbach et al., 1999; Van der Kloet et al., 2012), a generally benign trait characterized by deep, profound, and longstanding involvements in fantasy and imagery. The connection between vivid dreaming, fantasy proneness, and dissociation implies that creativity might be a personality trait strongly related to these constructs. Nevertheless, scientific reports on the association between creativity and dissociation are scarce (but see Perez-Fabello and Campos, 2011; Thomson and Jaque, 2012). Accordingly, an important goal of the present study is to examine the relation of creativity and dissociation.

One difficulty in testing the conceptual overlap between dissociative symptoms, fantasy proneness, and creativity is the potential bias introduced by the tendency to overendorse atypical answer options. That is, these constructs might correlate not because they are inherently related but because their overlap is the spurious result of overendorsement (Merckelbach et al., 2014). To circumvent this problem, in the present study we assessed creativity independent of self-reports. More specifically, we conducted a creative photo contest and asked participants to take 5 photos on 5 days that conformed to a designated theme. We chose the photo task rather than a divergent thinking task (e.g., anagram solving), as the former task would be more congruent with the visual nature of dreaming. We invited professional photographers and two clinical psychologists to rate the photos on creativity, originality, bizarreness, and quality. We hypothesized that: (1) highly dissociative people will rank higher in the contest than low-dissociative participants; (2) the most original photos will be taken on days in which the participant scored highest in acute dissociation; (3) unusual content of the photo or description will be more closely related to higher than lower dissociation levels; and (4) lower sleep quality (SQ) and more dream recall will be related to higher rankings on dissociation.

Materials and Methods

Participants and Procedure

Ninety two participants (55 women) were recruited via local email and poster advertisements. Inclusion criteria entailed an age of 18 years and older, proficiency in the English language, and access to either a camera or a mobile phone with camera function.

First, participants completed a baseline screening (see Measures) and were asked to compete in a photo contest. During the contest, they took 1 photo each day with a specific theme, for 5 consecutive days. Each morning, they received an e-mail with the assignment for that day. The assignments of the 5 days were always one word (day1: three; day 2: green; day 3: freedom; day 4: desire; day 5: home). Participants uploaded their photo via a password-protected website with a short description to accompany it. The assignment was to take a photo as creative as possible, adhering to the theme. The quality of the photo or the camera, or their professional technique was not important for the competition. Participants also completed the *Clinician-Administered Dissociative States Scale* (CADSS) and a short *sleep diary* every day in the morning (see Measures).

Next, the photos were ranked by two professional photographers and two clinical psychologists based on creativity, originality, and professional technique. We created an online photo ranking system that allowed the judges to view all of the photos for a particular day and rank them in a single session. The web site presented a viewing area to show the current photo and controls that permitted the judges to rate the photo or switch to the previous/next photo in the sequence. A thumbnail view was also presented to allow quick jumps to other photos in the sequence for comparison purposes.

The judges rated all photos on a scale between 0 (least creative) and 10 (most creative). They were asked to briefly view all submissions first, and then to rate each photo relative to all the other photos. They rated at least 1 photo with a grade of 0 and 1 photo with a grade of 10, and all other photos were scored with a grade in between, which produced a ranked list. The photos and their captions were also ranked on the basis of unusual content by the two clinical psychologists, who were selected as judges due to their specialties in imagery rehearsal and fantasy proneness. The participants with the most creative photos on most days won a prize (first prize: £250 Amazon voucher; second prize: £50 Amazon voucher) and their photos will be published in the university newsletter and other media sources. Only the creativity ranking of the photos determined the winner of the contest.

This study was conducted according to the code of ethics on human experimentation established by the Declaration of Helsinki (1964) and amended in Seoul (2008). Approval for the study was obtained from the Medical Sciences Inter Divisional Research Ethics Committee of the University of Oxford (MSD-IDREC-C1-2014-068).

Measures

Dissociative Experiences Scale II (DES; Cronbach's $\alpha = 0.94$; all α's from current study). The DES-II (Bernstein and Putnam, 1986; Bernstein-Carlson and Putnam, 1993) is a self-report scale of trait dissociation. Participants indicate on 100 mm visual analog scales (anchors: 0 = never; 100 = always) to what extent they experience 28 dissociative experiences in daily life. Van IJzendoorn and Schuengel (1996) provide meta-analytic evidence for the sound psychometric properties of the DES.

Iowa Sleep Experiences Survey (ISES; Cronbach's α = 0.87). The 18-item ISES (Watson, 2001) assesses the frequency of various sleep- and dream-related experiences, which are rated on a 7-point scale (anchors: 1 = never, 7 = several times a week). The ISES consists of two subscales that measure general sleep experiences and lucid dreaming. It possesses acceptable internal consistency (coefficient α = 0.85; Watson, 2001).

Gough Creative Personality Scale (CPS; Cronbach's α = 0.67). The CPS (Gough, 1979) is a self-report measure of creativity. It consists of 30 adjectives (e.g., capable, humorous, inventive) and the participant is asked to tick all the self-descriptive adjectives. Specific items reflect higher creativity, with higher total scores indicating greater creativity. Kaduson and Schaefer (1991) have reported on the high concurrent validity of the CPS.

Creative Experiences Questionnaire (CEQ; Cronbach's α = 0.82; Merckelbach et al., 2001). The 25-item CEQ measures fantasy proneness. The yes/no items tap daydreaming, intense fantasies, and imagination. The items were derived from case vignettes on fantasy proneness provided by Wilson and Barber (1983). Illustrative items are "I spent more than half of the day on fantasizing or daydreaming" and "Many of my fantasies are as vivid as a good movie." A total CEQ score is obtained by summing the items endorsed. Merckelbach et al. (2001) found adequate test–retest reliability and internal consistency.

Clinician-Administered Dissociative States Scale (Cronbach's α = 0.91−0.94). The 27-item CADSS (Bremner et al., 1998) is composed of 19 subject-rated items and eight oberver-scored items. Items are scored on a 5-point scale (0 = not at all, 4 = extremely). Bremner et al. (1998) found the CADSS to be a highly reliable and valid instrument to measure present-state dissociative symptoms. In the current study, we administered only the self-report items.

The *sleep diary* is a self-report instrument[1] that examines sleep patterns, adapted from the Consensus Sleep Diary (Carney et al., 2012), and contains questions about sleep patterns (e.g., time of lights out, number of awakenings during the night, time of final awakening, and time out of bed), and dream occurrence. We computed sleep pattern variables as follows: SQ was defined as the proportion of time asleep during the sleep period, calculated as the total sleep time divided by the time spent in bed, multiplied by 100. We also computed the average hours of sleep per night across the 5 days (HS). Participants completed the items every morning. Sleep diaries are a commonly used and valid means of collecting data regarding daily activities and sleep perceptions (Cheek et al., 2004).

Data Analysis

Statistical analyses were performed within the R statistical environment (R Core Team, 2013). Cronbach's α values were calculated to estimate internal consistency of the baseline and state measures. Pearson product-moment correlations between baseline and state measures were calculated. State and trait data were analyzed using mixed-effects models and regression analyses.

Results

Descriptives

Of the 92 participants, 72 participants (55 women; 15 men; 2 unreported) completed all assessments on all days and submitted all 5 photos. Their mean age was 35.8 years (SD = 16.9) and mean level of experience with photography was rated as 4.8 (SD = 1.8) out of a maximum score of 8, indicating that participants were interested in photography and regularly took photographs. A majority reported owning a digital bridge or single lens reflex camera, having some understanding of basic camera controls (shutter speed, aperture, ISO etc.), and using these controls to photograph interesting objects and experiences. The majority of participants were thinking about taking up photography as a hobby or interest. During the study, they displayed a mean level of motivation of 3.6 (SD = 1.1) on a 5-point Likert scale ranging from 1 ("Not motivated at all") to 5 ("Very motivated"). They slept an average of 7.2 h (SD = 1.5) per night during the 5 day study period. **Table 1** displays mean scores and Pearson product-moment correlations of the trait and state variables.

TABLE 1 | Mean scores (SD) and Pearson product-moment correlations of trait and state variables (*N* = 72).

	Mean **(SD)**	***DES***	***ISES***	***CEQ***	***CPS***
DES	13.68 (11.48)	–	–	–	–
ISES	35.11 (17.00)	0.54*	–	–	–
CEQ	9.37 (4.98)	0.73*	0.45*	–	–
CPS	12.57 (2.72)	0.31*	0.06	0.41*	–
CADSS	0.28 (0.42)	0.63 to 0.75*	0.40 to 0.53*	0.47 to 0.59*	0.21 to 0.35*
SQ	2.88 (0.72)	−0.15 to −0.23	−0.31to −0.19*	−0.20 to −0.05	−0.14 to 0.01
HS	7.2 (1.5)	−0.16 to 0.07	0.01−0.20	−0.26 to 0.10*	−0.22 to −0.02

*DES, Dissociative Experiences Scale; ISES, Iowa Sleep Experiences Survey; CEQ, Creative Experiences Questionnaire; CPS, Gough's Creative Personality Scale; CADSS, Clinician-Administered Dissociative States Scale; SQ, average sleep quality across the 5 days; HS, average hours of sleep per night across the 5 days. Correlations of state measures displayed in table are ranging from day 1 to day 5. *$p < 0.05$, *some p's < 0.05.*

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[1] A copy of this instrument can be obtained from the first author.

We found strong correlations among the trait measures of dissociation, unusual sleep experiences, fantasy proneness, and creative personality.

Relations Between Creativity and Trait and State Measures

The judgment panel ranked all the photos of the 5 days based on creativity, originality, bizarreness, and quality in adherence to the specific theme of each day. Scores were normally distributed for all raters. Internal reliability analyses as computed with Cronbach's alpha showed α's ranging between 0.63 and 0.73, with the exception of $\alpha = 0.36$ for day 3, displaying moderate consistency between the four raters. These are displayed in **Table 2** alongside Spearman's rank correlations between the 4 judges' creativity scores for each participant (averaged across the 5 days). All judge pairings were significantly correlated. Daily Spearman's rank correlations between the judges' creativity scores were also high. The judges' creativity and originality scores (averaged across the 5 days) were highly correlated ($r = 0.89, p < 0.05$). These were also high on a day to day basis (r's $= 0.51$–0.84, all p's < 0.05). Therefore, scores were averaged across raters, and we focused the majority of our analyses on the creativity score.

First, we explored the relation between the judges' creativity rankings and the trait and state measures; see **Table 3** for an overview. Mean state dissociation was significantly correlated with the creativity score ($r = 0.27$, $p < 0.05$), and the originality score ($r = 0.29$, $p < 0.05$), but not with bizarreness ($r = 0.11$, $p > 0.05$) and quality ($r = 0.19$, $p > 0.05$). Second, we examined the data from the daily sleep diary. Less SQ and fewer HS related to more bizareness in the photos of those days ($r = -0.27$, and $r = -0.29$, both p's < 0.05).

Furthermore, participants reported whether they recalled having a dream last night, and whether this dream had a positive or negative emotional salience. As expected, we found a negative correlation between how happy and how bad a dream was ($r = -0.54$, $p < 0.05$). We found no relation between the emotional salience of the dreams and creativity on the following day ($r = -0.04$, and $r = 0.04$ respectively, both p's > 0.05). Similar results were found for orginality ($r = 0.01$, and $r = 0.03$), and bizareness ($r = -0.03$, and $r = 0.02$), all p's > 0.05.

TABLE 2 | Spearman's rank correlations and internal consistency analyses (measured by Cronbach's alpha) between the creativity ratings of our 4 judges.

	Photo1 r	*Photo2 r*	*Clin1 r*	*Inter-rater reliability across days: Cronbach's α*
Photo1	–	–	–	Day 1 = 0.73 Day 2 = 0.63 Day 3 = 0.36 Day 4 = 0.65 Day 5 = 0.69
Photo2	0.46*	–	–	
Clin1	0.60*	0.59*	–	
Clin2	0.48*	0.35*	0.49*	

*Photo1, Professional photographer 1; Photo2, Professional photographer 2; Clin1, Clinical psychologist 1; Clin2, Clinical psychologist 2. *p < 0.05*

TABLE 3 | Correlations between mean state measures and average ratings of judges on creativity, originality, bizarreness, and quality (*N* = 72).

	Crea	*Orig*	*Bizar*	*Qual*	*CADSS*	*SQ*
Crea	–	–	–	–	–	–
Orig	0.89*	–	–	–	–	–
Bizar	0.53*	0.32*	–	–	–	–
Qual	0.79*	0.73*	0.34*	–	–	–
CADSS	0.27*	0.29*	0.11	0.19	–	–
SQ	−0.14	−0.06	−0.27*	−0.13	−0.21	–
HS	−0.08	−0.00	−0.29*	−0.13	0.08	0.24*

*Crea, Creativity average rating; Orig, Originality average rating; Bizar, Bizarreness average rating; Qual, Quality average rating; CADSS, Clinician-Administered Dissociative States Scale; SQ, average sleep quality across the 5 days; HS, average hours of sleep per night across the 5 days. *p < 0.05 (Critical value: r = 0.23).*

Finding Predictors of Creativity, Originality, and Bizarreness

In order to further explore the connection between the creativity rankings and the measures collected (see Measures), while allowing for variance both within and between subjects, we fitted mixed-effects models to the daily creativity data. For an overview of mixed-effects modeling, see (for example) Singer and Willet (2009).

First, we considered a random-intercepts model (model 0 in **Table 4**) and a random-intercepts model with a time slope (model 1). The addition of time to the model improved the fit to the data, with Akaike's information criterion (AIC) decreasing, and the likelihood ratio test also suggesting we retain this predictor.

Next, we added random slope effects, to give a random intercepts and slopes model (model 2). This allows for the effect of the day of the study on creativity to vary by participant. The AIC increased with this addition, and the likelihood ratio test also suggested to not retain the random slopes.

Finally, we included a covariate for state dissociation (model 3). By comparison to model 1, we found state dissociation worth retaining in the model, supported by the likelihood ratio test as well as a drop in the AIC. We found this model described the data best. It was not incrementally valuable to add HS, or SQ, to the random-intercepts model. Thus, a model with a random effect for each participant (i.e., subject-specific intercepts), and with a population-wide slope for the fixed effect of the day of the contest on their creativity, plus the fixed-effect covariate of state dissociation, was the preferred model[2].

We repeated these analyses for the originality ranking, which resulted in similar findings. We found that a model with a random effect for each participant, with a population-wide slope for the fixed effect of the day of the contest on their originality, and with a fixed-effect dissociation covariate, was the preferred model to predict originality rankings

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[2] The model formulae are:
$\text{Creativity} = \left(5.21 + \beta_1\right) - 0.19(\text{Day} - 1) + 0.59 * (\text{Dissociation}) + \varepsilon$,with $\beta_1 \sim N(0, 0.78^2)$.and$\varepsilon \sim N(0, 1.46^2)$.
$\text{Originality} = \left(6.13 + \beta_1\right) - 0.24(\text{Day} - 1) + 0.59 * (\text{Dissociation}) + \varepsilon$, with $\beta_1 \sim N(0, 0.72^2)$.and $\varepsilon \sim N(0, 1.58^2)$.

TABLE 4 | Summary of mixed-effects model fits for creativity rankings.

	Df		*AIC*	*BIC*	*LogLik*	*Deviance*	χ^2	*Pr* (> χ^2)
Model 0	3		1362.1	1373.7	−678.05	1356.1		
Model 1	4		1351.4	1366.9	−671.68	1343.4	12.74	<0.001
Model 2	6		1353.8	1377.0	−670.88	1341.8	1.62	0.45
		Estimate (SE)				***t***	***p***	
Model 3	5	0.59 (0.26)	1348.4	1367.8	−669.2	1338.4	2.268	< 0.05

($AIC = 1394.6$; $BIC = 1413.9$). However, this was to be expected with the high correlation between creativity and originality in our sample.

Furthermore, we explored whether the trait measures could predict the judges' rankings, averaged across the 5 days of the contest. We used best-subsets regression to explore potential models for each of our outcome measures. This analysis considers every possible combination of predictors for the outcome rankings. For each outcome, models with the smallest adjusted R^2 are then further considered.

None of the trait measures could predict the average creativity and originality rankings. However, we found that creative personality significantly predicted the bizarreness ranking, $F(1,68) = 4.05$, $p = 0.05$. However, in this model the explained variance in bizarreness was small; $adj\ R^2 = 0.04$.

Discussion

Our study investigated the relations among creativity, dissociation, and unusual sleep experiences. We found evidence for: (a) high correlations between dissociation and unusual sleep experiences and fantasy proneness, consistent with previous research (Knox and Lynn, 2014); (b) a high correlation between fantasy proneness and unusual sleep experiences (see also Van der Kloet et al., 2012; Watson et al., 2015); (c) a moderate correlation between dissociation and creative personality, and (d) no significant correlation between creative personality and unusual sleep experiences. Our findings are in line with Koffel and Watson (2009) who proposed that unusual sleep experiences, dissociation, and schizotypy belong to a common domain. We also found that state but not trait dissociation predicted creativity and originality in that more creative photos were taken on highly dissociative days. The link between trait dissociation and judged photo creativity did not appear to be direct, but rather depended on higher acute dissociative states on the specific days.

Although we found no connection between dissociation and rated photo bizarreness, fewer HS and poorer SQ were related to more bizarreness. These findings concur with the idea that sleep disturbances increase the likelihood of intrusions of sleep mentation into wakefulnes, consistent with previous studies in which sleep deprivation increased dissociative symptoms (Giesbrecht et al., 2007a; Van Heugten–Van der Kloet et al., 2015). Nevertheless, we did not find poorer sleep to be related to higher creativity. For the de-differentiation theory (Llewellyn, 2011) to be supported, we would assume disruptions in consciousness to go both ways. This would lead to disturbances during waking and sleep, thereby fostering loose associations and enhancing creativity. Thus, the link may be more complex and less direct than we anticipated. Perhaps minor sleep fluctuations over a number of days may not be sufficient to produce significant associations between dreaming and creativity, but these links may be more apparent with fluctuations in state dissociation. An alternative explanation for the absence of the link between sleep and creativity could be that bizarreness is a better indicator of associative thinking than artistic creativity, as bizarreness may reflect 'highly associative leaps' following sleep disturbance. Nevertheless, this hypothesis should be confirmed by future studies.

We also found that creative personality predicted photo bizarreness, although the explained variance was limited. Although the correlations that we found between state dissociation and creativity ratings and between sleep loss and bizarreness were modest, they, nevertheless, highlight an important point: most previous studies of dissociation, unusual sleep experiences, and fantasy proneness are entirely based on self-reports (e.g., Merckelbach et al., 1999, 2001; Van Heugten–Van der Kloet et al., 2014), which are vulnerable to the criticism that overlap among these constructs may be an artifact of overendorsement of atypical items (e.g., response bias). We sidestepped this problem by using ratings of independent judges and found meaningful correlates of state dissociation and self-reported sleep loss with creativity and bizarreness.

The relations of dissociation to creativity and of sleep loss to bizarreness are harmonious with the idea that hyperassociativity is a key feature of the dissociation-sleep link. That is, sleep loss may 'push' sleep mentation toward the waking end of the consciousness continuum, which may, in turn, contribute to both (a) hyperassociative cognition that marks episodes of dissociation and dissociative conditions (Van Heugten–Van der Kloet et al., 2013; see also **Figure 1**) and (b) creative thinking, likewise characterized by fluidity of associations (Chakravarty, 2010).

Several authors have commented on the overlap between dissociative symptoms, psychotic–like experiences (Giesbrecht et al., 2007b), and dreaming (Koffel and Watson, 2009). Interestingly, the associations among the dream self, dissociative symptoms, and abnormal self experiences in schizophrenia is highly complex. The dreaming state is generated as the brain acts as a closed system, detached from the environment (D'Agostino et al., 2013). A disturbance in the feeling of presence of the self situated in the world is considered to be one of the hallmarks of the schizophrenic prodrome. Indeed, it may be an underlying vulnerability marker, as it seems independent of symptom manifestation and is evident in schizotypal clinical conditions as well (Nelson et al., 2009). This sense that the self is alienated from the experience manifests in various forms in schizophrenia and other conditions, most notably as depersonalization and derealization experiences, which are considered core dissociative symptoms found to be correlated with schizotypy (Lynn et al., 2012).

A number of caveats pertinent to the current study merit consideration. Our population was predominantly female, and the sample size was relatively small. We heavily relied on self-report questionnaires and internal consistency was low at one point in the study. Nevertheless, the questionnaires used in this study were all well-validated with good psychometric properties. Although the internal consistency of our raters was moderate-to-high, the photography ratings are, nevertheless, subjective. Finally, the levels of state dissociation in our sample were relatively low and variations in sleep were minor. Accordingly, it may have been difficult for significant changes to emerge due to lack of variability. Future studies could consider a longer study period (e.g., 3 weeks of sleep data would be optimal) and targeting patients with significantly increased dissociation levels in order to increase generalizability.

These caveats aside, our findings contribute to our understanding of dissociative symptomatology. Perhaps the link between dissociation and creativity may be explained as the product of a modicum of de-differentiation between waking and dreaming that may be advantageous insofar as it enhances artistic creativity. Although some people with an attenuated form of psychopathology may be highly talented (e.g., Isaac Newton), psychopathology may arise when waking and sleep/dreaming states become severely de-differentiated. Or, as Kant eloquently wrote: "The lunatic is one who dreams whilst awake" (Freud, 1999).

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Dreams as a source of supernatural agent concepts

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We present a theory of the creativity of dreams as well as psychopathology of religious delusions with respect to production of fundamental forms of religious cognition—specifically supernatural agent (SA) cognitions. We suggest that dream cognitions are particularly efficient at producing highly memorable and impactful experiences with SAs because dreams involve three processes that are prerequisites for the generation of god concepts: (1) mental simulations of alternative realities, (2) theory of mind attributions to the extra-natural dream characters and divine beings, and (3) attribution of ultimate value (exemplified by 'good spirit beings'), and dis-value (exemplified by demonic monsters) to the supernatural dream characters. Because prefrontal cortex is deactivated during rapid eye movements (REM) sleep agentic impulses and internally generated ideas are not reliably attributed to Self or dreamer. Instead an exaggerated degree of agency is attributed to these supernatural dream characters who are then embedded in stories in dreams and in myths of waking life which explain their supernatural abilities. These dream-based SAs are salient characters that are processed in sleep-related memory systems according to rules of Lleweelyn's ancient art of memory model and therefore more easily remembered and reflected upon during waking life. When REM sleep intrudes into waking consciousness, as is the case with some forms of schizophrenia, religious delusions are more likely to emerge.

Keywords: dreams, creativity, supernatural agents, religion, REM sleep

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Introduction

In this paper we highlight dreams as a source of creativity-specifically in the realm of religious ideas. We also detail a role for dreams in production of religious delusions associated with certain forms of psychopathology such as schizophrenia. For over a century anthropologists working in every part of the world have amply documented the importance of the dream as a primary source for religious ideas and practices of traditional peoples (Tylor, 1870; Lincoln, 1935; Grunebaum and Caillois, 1966; Tedlock, 1992). In many traditional societies dreams were considered direct, experiential evidence of a spirit realm (see reviews in Bulkeley, 2008a; Mittermaier, 2010). Many trial peoples interpreted their dreams as cases where the dreamer's soul wanders outside the body and communes with the gods and spirit beings of the spirit world (e.g., Gregor, 1981; Lohmann, 2003a,b,c). Harner (1984), reports that the South American Jívaro consider dreams to be populated by spirit beings who often are, or become the focus of their sacred rituals and stories. The Zuni and Quiché Maya traditions studied by Tedlock (1992) see dreams as direct communications from sacred ancestors. The Tikopia (Firth, 2001) in Polynesia see many dreams as direct communication of spirit beings to the dreamer.

The characters populating these dreams can be described, in the language of the cognitive science of religion, as *supernatural agents* (SAs): non-human entities with autonomous powers and intentions. Their bodies may not be clearly seen, but they do have minds and they frequently have unusual powers far beyond the capabilities of ordinary agents (e.g., flying, time-travel, mind-reading; Boyer, 2002). More specifically, these SAs can be characterized as "minimally counterintuitive." "Counterintuitive (CI)" means their unusual abilities violate our intuitive assumptions about what normal agents can and cannot do. They are "minimally" CI because they violate *some* of our intuitive assumptions, but not *all* of them. They are just CI enough to draw attention and arouse curiosity without overwhelming comprehension, making them easier to remember, and describe to other people. CI concepts can be scored in narratives (Barrett, 2008). If we use Barrett's scoring criteria for CI concepts we find that dreams are filled with them (McNamara, unpublished data).

Boyer argued that the CI properties of SAs makes them more memorable. If an agent is too CI and violates our assumptions in too many ways, we will have more difficulty recalling its characteristics and telling other people about it (a crucial factor in how religions spread over time). However, if an agent is not CI enough, it will not make a strong enough impression on awareness, and it will thus sink into general forgetfulness. The notion of "minimally counterintuitive" SAs is intended to designate a cognitively optimal set of features that give god concepts a strong, innately compelling appeal to the human mind.

Despite the abundance of anthropological evidence linking people's beliefs in SAs with dream experiences, few efforts have been made to explain the brain/mind processes connecting dream cognitions and religious cognitions. In this paper we present evidence in favor of the hypothesis that *supernatural agent cognitions are significantly influenced by nightly dream content patterns*. We present several interrelated strands of evidence to support the plausibility of this idea and explain the mechanisms involved. We begin with an overview of the neurobiology of rapid eye movements (REM) and non-rapid eye movement (NREM) sleep states insofar as this neurobiology relates to dream cognitions. We then review historical and cross-cultural evidence linking dream cognitions to SA cognitions. We conclude with a presentation of a theory as to how dream cognitions generate SA cognitions.

REM and NREM Sleep States

When measured electrophysiologically, sleep (in humans) is composed of four major stages. The first three (N1–N3) stages constitute NREM sleep, and are best described by polysomnographic and electroencephalographic (EEG) criteria. The fourth stage is not part of NREM sleep and is characterized by periodic or phasic bursts of REM under the closed eyelids. REM sleep is indicated by EEG data, electroculographic activity, and a reduction in electromyographic (EMG) activity. EMG electrodes are usually placed under the chin, and indicate when the muscle paralysis characteristic of REM sleep occurs (Rechtschaffen and Kales, 1968).

Rapid eye movements and NREM sleep states alternate throughout the night in a period of about 90 min. Stage N1 is a transitional stage to N2 or light sleep. N3 is composed of slow-wave sleep which is particularly potent during the childhood phase of development. NREM stages dominate the first third of the night, while REM dominates the last third (Carskadon and Rechtschaffen, 2000). A sleep cycle is defined as a period of NREM sleep followed by a period of REM sleep. During a single night, a person will progress through three or four NREM–REM sleep cycles, each lasting 90–110 min and becoming progressively longer through the night. Usually, the NREM period will last about 80 min or longer, followed by a REM period that can be as short as 1 min in the early cycles. Toward the morning REM periods can last as long as 45 min.

Rapid eye movement sleep accounts for about 22% of total sleep time in humans. The cortex, particularly the limbic region, is very highly activated in REM. The phasic aspects of REM, such as intermittent muscle twitching, autonomic nervous system (ANS) discharges, and REM, occur in some mammals in association with bursts of pontine-geniculo-occipital waves. Mammals (with the possible exception of humans) also exhibit a theta rhythm in the hippocampal formation during REM night.

Rapid eye movement's tonic characteristics are a desynchronized EEG, penile erections, and atonia of the antigravity muscles. Its phasic characteristics include bursts of REM under the closed eyelids, myoclonic twitches of the facial, and limb muscle groups, increased variability in heart rate, respiration, and blood pressure, and ANS discharges. Other correlates of REM include effects on release of selected hormones – especially growth factors. Virtually all mammals (with some exceptions such as certain sea mammals) exhibit both SWS and REM sleep.

Rapid eye movements sleep demonstrates high activation levels in limbic/amygdaloid sites, in dopaminergic, and cholinergic circuits but deactivation of dorsolateral prefrontal cortex sites (Maquet et al., 1996; Braun et al., 1997; Maquet and Franck, 1997; Nofzinger et al., 1997; Hobson et al., 1998; Dang-Vu et al., 2007; Hobson, 2007), as well as cessation of activation in the noradrenergic locus ceruleus and the serotoninergic raphe nucleus. Stage N2 sleep involves higher activation levels in filiative paralimbic regions in the cortex relative to REM sleep and to the deep sleep of NREM stage 'slow wave sleep.' Larson-Prior et al. (2009) examined MRI-blood oxygen dependent signal functional connectivity using conventional seed-based analyses in several cortical sites as healthy young adults entered NREM sleep from wakefulness. Functional connectivity was maintained in cortical networks in NREM sleep. Thus both NREM N2 stage sleep and REM sleep are characterized by brain activity patterns that can support complex cognitive processes.

Dream content differs to some extent across REM and NREM sleep states, and so SA cognitions may also differ in relation to sleep states. For example, using the standardized / Hall Van de Castle dream scoring scales (Hall and Van de Castle, 1966; Domhoff, 1996), dreams obtained from N2 stage sleep tend to be more thought-like, less bizarre, and less emotional than dreams obtained from REM (Domhoff, 1996). McNamara et al. (2005)

scored REM and NREM dreams and wake reports for number and variety of social interactions. We found that aggression levels were higher in REM vs. NREM, or wake reports and that conversely, dreamer-initiated friendliness was more characteristic of NREM than REM. These findings were recently replicated using standard polysomnographic and EEG sleep-staging techniques (McNamara et al., 2010). One straightforward hypothesis flowing from these data with respect to SA cognitions is that friendly spirits would more often though not exclusively be encountered in NREM dreams and less friendly or demonic spirits would be encountered more often, though not exclusively in REM dreams.

Rapid eye movements physiology can intrude into daytime consciousness and when it does it may create delusional states. It is well established that sleep deprivation reliably produces compensatory attempts to enter REM throughout the day resulting in REM microsleeps as well as reports of dreamy states and dissociative symptoms.(Limosani et al., 2011; Palagini and Rosenlicht, 2011) The role of REM-irruptions into waking consciousness is well-recognized in narcolepsy where the associated experience is the production of hypnagogic hallucinations. Mahowald et al. (2011) and van der Kloet et al. (2012) review a range of evidence which demonstrates that dissociative symptoms such as absorption, derealization, depersonalization, and other symptoms associated with a range of psychiatric disturbances originate from sleep. REM intrusion has been reported to contribute to symptoms and delusional states in schizophrenia (Gottesmann and Gottesman, 2007; Cohrs, 2008). Religious delusions and unusual religious experiences are more frequent among schizophrenic patients with positive symptoms compared to that of the general population (Siddle et al., 2002; Kimhy et al., 2005; Green et al., 2006; Huguelet et al., 2006; Mohr et al., 2010). Religious delusions are erroneous beliefs that a SA is shaping the experiences of the rooted patient. The content of religious delusions are typically persecutory (e.g., ill-intending evil spirits) and involve alterations in sense of self including grandiosity or extreme self-denigration and these delusions are even more resistant to rational disconfirmation than other types of delusions.

Having reviewed the fundamental neurology of REM and NREM sleep states as well as ways in which REM and dreams may impact psychopathology we turn now to evidence for the view that SA cognitions are causally related to dream cognitions.

Dreams in History of Religions

According to early anthropologists like Tylor (1870) it seems probable that humans first entertained the idea of a spirit realm because they directly experienced such a realm in their dreams. Researchers working in many different parts of the world have found that people in traditional societies treat dreams as the sources of their religious ideas, including their concepts of their gods and other supernatural beings (e.g., Gregor, 1981 on Amazonia; and Lohmann, 2003a,b,c on Oceania; and Tonkinson, 1974, on Aboriginal Australia; Shweder and LeVine, 1975; Keesing, 1982; Shweder and Bourne, 1982; Shaw, 1992; Hollan, 2003; Robbins, 2003). It is likely that ancestral populations also treated them as such. Dreams were considered proof of the gods and a spirit realm since dreams were involuntary and emotionally vivid experiences that involved the dreamer's soul encountering other beings including long deceased relatives and so on. Dreams have therefore played a major role in the historical evolution of religions.

Although the first glimmers of religious consciousness likely occurred in tandem with Neanderthal burials some 100,000 years before the present, the first clear signs of the emergence of SAs occurs in the hundreds of cave art sites that have been dated to the Upper Paleolithic. In the Chauvet cave that dates to some 28,000 years ago, there are many images of therianthropes or human-animal hybrids that very likely depicted SAs. Ancient rock art from all over the world also very often depicts masked human forms and therianthropes. The Tassili rock art of the Sahara depict therianthrope SAs that date to a time (the Neolithic and perhaps earlier) when the Sahara still contained grasslands where flocks of animals could be hunted. The rock art of the San of South Africa depict larger than life hunters garbed in animal masks and skins. The rock art of native tribes of Australia that date back many 1000s of years also depict similar therianthropes.

The examples could be multiplied many times over. This suggests that SA figures first occurred in the visionary dreams of the people who painted these images. A number of scholars have argued that traditional diviners/healers known as *shamans* may have painted some of these images (Lewis-Williams, 2002; Hayden, 2003). Current ethonographic evidence (Eliade, 1964) suggests that shamans contact their spirit helpers and divine being via two methods: ecstatic states induced by entheogens, or other methods and via dream states. We have evidence that that is how the shamans of the upper paleolithic derived their god figures as well. Right at the beginning of the upper Paleolithic we have an image of a shaman in headdress with antlers and animal skins at Fumane cave in Italy dated to 35,000 years ago. The "sorcerer" image from the cave at Les Trois Freres shows a man wearing animal skins, arms outstretched like a horse rearing with a reindeer antler headdress, owlish eyes, bear paws, and human beard. Another image can only be seen by lowering oneself down via rope into the famous 'shaft' at Lascaux. The image should really be termed a composition as it depicts some sort of interaction between a wounded bison and a therianthropic figure lying below the bison. The figure is of a man with an erection and a bird-like head. Standing upright next to the man is his staff. The staff has the same sort of bird perched on top. The bird is probably the totem animal for this shaman. Many shamans believe they become birds when they fly into the heavens when traveling to the spirit world. The fact that the man has an erection suggests that he is dreaming in REM sleep (dreams and erections invariably occur in association with REM). The shaman is dreaming the sacrifice of the bison and the bison is considered a sacred spirit being.

We have seen that dreams likely played a role in creation of religious consciousness at the dawn of the human adventure. They have continued to play a role in religious consciousness ever since (Bulkeley, 2008a,b). All the world's religious traditions have pointed to dreams as spiritual events of extreme importance in the transformation of the self and with respect to communication with the spirit world (see O'Flaherty, 1986; Jedrej and Shaw, 1992; Irwin, 1994; Young, 1999; Mittermaier, 2010). This is not the place to document the full extent of the multiple roles of dreaming in the world's religions, but two highlights can be mentioned to suggest the close connection between dreaming experience and religious concepts.

First is a Biblical story, sacred to Jews, Christians, and Muslims alike, about the patriarch Jacob, and his dream theophany, reported in Genesis 28. The dream occurred after Jacob had tricked his blind father Isaac into giving him the blessing that should have gone to his older brother, Esau. Enraged at this trickery, Esau made a vow to kill Jacob. However, their mother, Rebekah, overheard Esau, and she arranged for Jacob to visit relatives in a distant village, giving him the opportunity to escape before his brother can find and murder him. Away Jacob went, out into the wilderness. One night during his solitary journey through the deserts of ancient Canaan he lay down, placed a stone under his head for a pillow, and went to sleep:

> "And he dreamed that there was a ladder set up on the earth, and the top of it reached to heaven; and behold, the angels of God were ascending and descending on it! And behold, the Lord stood above it, and said, 'I am the Lord, the God of Abraham your father and the God of Isaac. The land on which you lie I will give to you and to your descendants; and your descendants shall be like the dust of the earth, and you shall spread abroad to the west and to the east, and to the north, and to the south; and by you and your descendants shall all the families of the earth bless themselves. Behold, I am with you and will keep you wherever you go, and will bring you back to this land; for I will not leave you until I have done that of which I have spoken to you."
>
> (Gen. 28:12–15, RSV; Metzger and Murphy, 1991).

Jacob awoke from this dream filled with wonder, surprise, and fear. "Surely the Lord is in this place; and I did not know it," he says to himself. "How awesome is this place! This is none other than the house of God, and this is the gate of heaven." At a time of deep personal uncertainty, with his life in danger and his future totally unknown, Jacob experienced an overwhelming dream vision of heavenly angels, with the reassuring words of God to soothe his fears and rouse his procreative energies.

Whether or not there was really a man named Jacob who actually had this dream, we can recognize in this Biblical story an early awareness of the wonder-working power of dreaming and its influence on religious beliefs about SAs.

A second example, not nearly as well known, comes from an ancient Japanese Buddhist context. The 11th century C. E. woman known as Lady Sarashina (her real name is not known) recorded a number of dreams in her diary, translated as *As I Crossed a Bridge of Dreams* (Morris, 1971). Toward the end of her life, after her husband had died and her hopes for working in the romantic world of the Imperial palace had been dashed, she described the following, which occurred on "the thirteenth night of the Tenth Month of the third year of Tenki":

> "[I] dreamt that Amida Buddha was standing in the far end of our garden. I could not see him clearly, for a layer of mist seemed to separate us, but when I peered through the mist I saw that he was about six foot tall and that the lotus pedestal on which he stood was about four feet off the ground. He glowed with a golden light, and one of his hands was stretched out, while the other formed a magical sign. He was invisible to everyone but me. I had been greatly impressed but at the same time frightened and did not dare move near my blinds to get a clearer view of him. He had said, 'I shall leave now, but later I shall return to fetch you.' And it was only I who could hear his voice."
>
> (Morris, 1971, 107).

This dream of intimate communion with a SA made a big impact on Lady Sarafina—"thereafter it was on this dream alone that I set my hopes for salvation." Like Jacob, her waking life seemed bleak and hopeless, and in that emotional context she has a vivid, highly memorable dream of a beneficent deity who provides reassurance and a revived sense of hopefulness about the future.

Many more cross-cultural examples could be offered, but these should be sufficient to indicate the strong and widely felt impact that dreams have had on people's religious and spiritual concepts throughout history.

Dreams as a Source for Religious Cognitions

We have summarized the view that dreams have been a key source for religious cognitions and experiences throughout the history of religions. We now present a theory as to how dreams act as a source for religious cognitions.

First, for many people dreams present direct evidence of a spirit realm and of disembodied spirits. For example, in so called visitation dreams the dreamer sees a beloved friend or relative who in waking life has died. In the dream the loved one delivers a message to the dreamer that he or she is well. The dreamer awakens with an absolute conviction that the person in the dream was really, truly the loved one. The "visitation" is often described as so real and lifelike that grief over the death of the loved one is significantly diminished and the dreamer feels that contact with the deceased is real.

Second, many people experience direct contact with a supernatural being in their dreams. The dream of Lady Sarafina mentioned above is a good example of such a dream. The contact with a divine figure is once again experienced as intensely real, awe inspiring and definitive. The impact of this contact with a divine being is so significant for the dreamer that it changes his or her life for months or years thereafter.

We suggest that dream cognitions are particularly efficient at producing highly memorable and impactful experiences with SAs because dreams involve three processes that are prerequisites for the generation of god concepts: (1) mental simulations of alternative realities, (2) theory of mind (ToM) attributions, and (3) computation of ultimate value (exemplified by 'good spirit beings'), and dis-value (exemplified by demonic monsters).

Dreams as Mental Simulations

Many theorists have attempted to characterize the species of cognition one sees in dreams. One proposal that has received some preliminary empirical support is that many dreams specialize in mental simulations of worlds or states of affairs different from the waking world. Of course the spiritual realm is one such "world" for most religious traditions. McNamara et al. (2001) has proposed that mental simulations of alternative worlds or of ultimate realities can be either oriented to the past, in which case they are counterfactuals, or they can be oriented toward the future, in which case they are examples of prospection. A third form of simulation important for dreams is projection of the self as in ToM attributions. We will discuss ToM attributions below. Here we remark on past- and future-oriented mental simulations that occur in dreams.

Dreams very likely play a role in "episodic prospection" or "episodic future thought" (Spuznar, 2010) such as planning, development of goals, generation of desires, mental simulations of possible worlds, imagination of future scenarios, and contingencies, and daydreaming about possibilities. For example, in dreams the dreamer is virtually always desiring, planning, imaging, plotting, striving, simulating possible worlds, and in general aiming at some future outcome. Dreams are goal driven and that is why they are sometimes spoken of as narratives, stories, or episodes.

McNamara et al. (2001, 2002) has discussed past-oriented counterfactual simulations in dreams. Counterfactuals in logic characterize conditions under which some state of affairs might have been true. In philosophy and in language semantics counterfactuals have been used to characterize modal event logics and to use possible world scenarios to evaluate formal languages. In economics counterfactuals are crucial to a range of theories concerning risk and decision-making rules under conditions of regret and attempts to avoid losses. In psychology and cognitive neuroscience counterfactuals are treated as mental simulations of possible worlds or states of affairs.

Regardless of the various ways in which counterfactuals are treated in these disparate intellectual disciplines, the common denominator is that they are mental simulations of what might have happened if I had chosen differently or performed slightly differently. Their appearance in dreams have been documented by McNamara et al. (2002).

Theory of Mind Attributions

Theory of mind attributions are ubiquitous in dreams. Schweickert and Xi (2010) found an average of nine instances of ToMs per dream in a set of dreams they studied. Thus dreams satisfy one of the main requirements that many theories of religious cognition demand for thinking about SAs, namely the capacity to generate ToM attributions. But we believe that the generation of SAs requires more than mental simulation of possible worlds and/or the capacity to do ToM attributions. To ascribe religious significance to a super-natural being in a dream or wake state I need to do more than to simply cognize or realize that that being has a mind like mind, I also have to reverence or fear (or both) that being; I have to in short impute value or significance to that being.

Computation of Value

Although many authors have asserted that the proximate origins of god concepts are ToM attributions, it is not clear to us that the mind-reading system, by itself, produces the kinds of SAs that generally populate religious ideologies or traditions. It is not clear how hierarchical meta-representations or processes like these yield a deity that we feel awe and reverence for. For most human beings throughout history reading the god's minds was not a primary goal. Rather it was establishing a relationship with the god that mattered because that god represented power and one's highest values. For most human beings gods demand worship or reverence and often fear. A human being cannot be in the presence of a thing of immense value and power without some sort of emotional response like reverence, devotion, or commitment.

It is this latter stance of *commitment to the god* that is missing from ToM and related accounts of religious cognition. We not only attempt to know and be known by a god. We attempt to relate to them, to unite ourselves to them, or in the case of demonic SAs, we attempt to flee/avoid them. There is an emotional response because matters of ultimate concern are involved where religious cognition is concerned.

We have mentioned above how dreams typically involve the dreamer pursuing or trying to attain to some desired state or to avoid a fearful outcome. These are obviously instances of perception of value and pursuit of value. The neurobiology of REM and NREM sleep states is now understood to involve forebrain mesocortical dopaminergic systems that directly compute value and dis-value (Perogamvros and Schwartz, 2012). In addition, with respect to REM itself, replicated findings have shown decreased anterior-posterior EEG coherence at gamma frequencies during REM vs. NREM sleep (Perez-Garci et al., 2001; Corsi-Cabrera et al., 2003, 2008) as well as in phasic vs. tonic REM sleep (Corsi-Cabrera et al., 2008). Coherence decreases appear to reflect limbic and amygdalar activation during REM sleep that is particularly enhanced during phasic REM sleep. Limbic and amgdalar systems are core systems involved in the computation of value. REM sleep demonstrates high activation levels in midline, ventral paralimbic areas, including medial prefrontal cortex, along with deactivation of lateral prefrontal cortices (Maquet et al., 1996; Braun et al., 1997; Maquet and Franck, 1997; Nofzinger et al., 1997, 2004) identify a midline anterior paralimbic areas that includes both subcortical areas such as basal forebrain, hypothalamus, ventral striatum, and hippocampus as well as paralimbic cortices such as insula, anterior cingulate, orbitofrontal cortex, and supplementary motor area. Reactivation of these paralimbic area, as well as deactivation of dorsal prefrontal regions with the transition into REM sleep has now been widely replicated (reviewed in Maquet et al., 2005; Nofzinger et al., 2006; Pace-Schott et al., 2009).

In short, the phenomenology of dreaming and the neurobiology of sleep suggest that dreaming cognition reflects the processing of value-related information. The fact that both dreams and religious cognitions are particularly concerned with the computation of ultimate values provides one more empirical link between them.

To summarize, dreams exhibit the three core functional capacities that are required for production of SAs: mental simulations of other worlds, ToM attributions, and computations of ultimate value.

This means all humans are endowed with brains innately primed to daily generate god concepts in dreaming.

Mechanisms

But how do dreams do it? At a minimum, we assume that the dreaming mind/brain constructs SAs via the ascription of agency to selected "other" characters in dreams. When a superabundance of agential attributes are attributed to these characters we get a divine being. Now the reason the dreamer ascribes agency to other characters in dreams is due to change in the normal way in which agency is constructed in the normal course of daily events in waking life. We discuss the construction of the sense of agency in waking life next.

Cognitive Models of Agency

Most of us can think inward thoughts and know that we are the source of those thoughts. However, schizophrenics, people with active bipolar disease and other individuals with neuropsychiatric disorder do not understand or believe that they are the source of the thoughts in their heads. How does this happen?

To see how someone can fail to see their own thoughts or actions as issuing from themselves we need to first say a little about how the predictive brain works to confirm its own actions. Most neuroscientists believe that the way in which this is accomplished is that whenever we think a thought or issue an action the brain issues an unconscious prediction of the predicted effects of that action or thought in the real world. If those predicted effects occur then the brain gets the confirmation it needs to conclude that the action or thought came from itself. If unpredicted effects occur then the brain needs to do further work to figure out whats going wrong. In a neuropsychiatrically impaired individual that further work is impeded or not done at all so the brain concludes that the thought or action must have come from outside the self or from some other being.

In short, the subjective experience of ownership of one's own thoughts and of control over sensory events emerges from an unconscious comparison between intentional and predicted /anticipated effects of one's actions: if there is a match, there is an increased tendency to experience the effect as self-caused, whereas a mismatch between anticipated and actual effect increases the tendency to attribute the effect to an external cause. The brain uses sensory feedback mechanisms wherein sensory effects of the action are assessed, to determine if there is a match or mis-match between intended vs. predicted effects of the action. If predicted effects occur then sensory feedback will be attenuated relative to a case where anticipated effects do not occur.

In REM dreaming we know that the prefrontal cortex activation levels are downregulated relative to waking levels. It is entirely possible therefore that the normal attenuation process of sensory feedback does not occur as efficiently as it does in waking. Thus the dreamer may conclude that the source of the efferent signals that arise from intentional scenarios that occur in dreams is not himself, so he therefore ascribes it to some other animate being in the dream. If there is no match between predicted and actual effects (and there cannot be in the dream) then there is little or no basis for ascribing intentional actions to the self and a corresponding increased pressure to ascribe them to another character who is invested with a very strong sense of agency-thus a divine being.

Although we know of no direct empirical studies on dream content that unequivocally links the REM-associated diminution in agency in the dreamer with a corresponding increase in agency in a special OTHER dream character, we think examples abound in the dreams we all have each night. Consider the ubiquitous dream theme of the dreamer attempting to escape from a pursuer. The dreamer seems unable to run fast enough to evade the pursuer or find ways to stop the pursuer who becomes more frightening as he advances on the dreamer. Or consider the norms on dream content variables derived from the Hall and Van de Castle standardized scoring system used now in hundreds of dream content studies (see Domhoff, 2003 for review). "Victimization" of the dreamer is reported in greater than 65% of dreams; self negativity appears in 66% of dreams; dreamer-involved success is found in less than 50% of dreams and misfortunes for the dreamer occur in greater than one third of dreams. Clearly most dreams involve setbacks or a diminution of agency in the dreamer. New research should assess potential links or quantitative correlations between the appearance of misfortune for the dreamer and greater success, power, or vividness for an opposing dream character.

Once a dream character has been invested with magical powers of agency and power in a dream these privileged characters then need to be processed specially so that they are selectively remembered as "special" during waking life. Llewellyn's recent theory of the ways in which REM and NREM sleep states use classical mnemonic processes to encode memories can help explain why "special" beings are so often remembered as part of dreams: in Llewellyn's model elaborative encoding in REM can, at least partially, be understood through ancient art of memory (AAOM) principles: visualization, bizarre association, organization, narration, embodiment, and location. Visualization of a divine being occurs in order to instantiate the required ascription of agency to a character after self ascription fails. Once visualization of a divine being occurs his or her special powers are put on display in a dream scenario thus forming bizarre associations with the figure. The encounter with the divine being, as in lady Serafina's dream above, occurs in a special sacred location and thereby elicits intense emotion. Finally the encounter between the dreamer and the divine being is embedded in a narrative derived from the local culture that generally has the deity imparting some message to the dreamer.

Conclusion

There can be little doubt that dream experiences have been thoroughly intertwined with the religious beliefs, practices, and experiences of people all over the world, throughout history. Although dreams are difficult to study scientifically, the sheer fact of their psychological and cultural ubiquity makes them an important topic for brain-mind research as well as for a scientific theory of religion. We have argued that new advances in the cognitive science of religion, particularly regarding SAs and the cognitive foundations of agency, can illuminate some of the neurological processes at work in dreaming that naturally lend themselves to attributions of special powers to "special characters/beings" in dreams and therefore to religious meaning and purpose.

We have also reviewed evidence suggesting that some psychiatric symptoms such as dissociative states and delusions have been linked with REM parasomnias and intrusion of REM into waking consciousness (due to sleep deprivation or to disease related breakdown in normal sleep architecture). In those psychiatric disorders that evidence sleep deprivation and REM fragmentation as well as religious delusions such as schizophrenia, the mechanism producing religious delusions may be illuminated by some of the links between dreams and SA cognitions we discuss in this paper.

It is beyond the scope of this paper to discuss possible methods of influencing, shaping, or guiding this religion-generating capacity of dreaming. We can point to examples like the dream incubation rituals performed at the ancient temples of the Greek healing god Askelpius, and suggest that these practices were effective because they skillfully channeled all mental and physical energies toward the healing process. The brain is not an isolated organ; every individual has been raised in a cultural environment that shapes the functioning of the mind in waking and in dreaming. Future research should consider exploring the cultural and psychological dynamics underlying these ritual practices.

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The role of REM sleep theta activity in emotional memory

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While non-REM (NREM) sleep has been strongly implicated in the reactivation and consolidation of memory traces, the role of rapid-eye movement (REM) sleep remains unclear. A growing body of research on humans and animals provide behavioral evidence for a role of REM sleep in the strengthening and modulation of emotional memories. Theta activity—which describes low frequency oscillations in the local field potential within the hippocampus, amygdala and neocortex—is a prominent feature of both wake and REM sleep in humans and rodents. Theta coherence between the hippocampus and amygdala drives large-scale pontine-geniculo-occipital (PGO) waves, the density of which predicts increases in plasticity-related gene expression. This could potentially facilitate the processing of emotional memory traces within the hippocampus during REM sleep. Further, the timing of hippocampal activity in relation to theta phase is vital in determining subsequent potentiation of neuronal activity. This could allow the emotionally modulated strengthening of novel and gradual weakening of consolidated hippocampal memory traces during REM sleep. Hippocampal theta activity is also correlated with REM sleep levels of achetylcholine - which is thought to reduce hippocampal inputs in the neocortex. The additional low levels of noradrenaline during REM sleep, which facilitate feedback within the neocortex, could allow the integration of novel memory traces previously consolidated during NREM sleep. We therefore propose that REM sleep mediates the prioritized processing of emotional memories within the hippocampus, the integration of previously consolidated memory traces within the neocortex, as well as the disengagement of consolidated neocortical memory traces from the hippocampus.

Keywords: REM sleep, emotional memory, encoding, acetylcholine, habituation, theta activity

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Introduction

Though the body may seem inert during sleep, the brain most definitely is not. Mammalian sleep cycles through multiple electrophysiologically and neurochemically distinct sleep stages. These stages are generally split into two categories, based on the occurrence of rapid-eye movements (REMs), i.e., REM and non-REM (NREM) sleep. While evidence strongly supports a pivotal role of NREM sleep in memory consolidation, the function of REM sleep remains elusive.

In this review, we propose that REM sleep represents a unique brain state that allows the emotionally modulated integration and recombination of neocortical memory traces previously consolidated during NREM sleep. In addition, we suggest that REM sleep is involved in the gradual disengagement of successfully consolidated memory traces from the hippocampus—thus mediating the decontextualization of novel memories, allowing generalization, abstraction, etc. To support this, we initially review behavioral evidence linking REM sleep and emotional memory processing in both rodents and humans. We then discuss how this relationship may be mediated by electrophysiological (in particular theta) activity within the hippocampus, amygdala and neocortex during REM sleep.

REM vs. NREM Physiology in Humans and Rodents

REM and NREM sleep differ remarkably in several ways: while NREM sleep is characterized by high amplitude, low frequency (0.3–4 Hz) electroencephalographic (EEG) activity reflecting synchronization across large neuronal populations, the low-amplitude, mixed frequency EEG activity observed during REM sleep more closely resembles that of quiet wake (Llinas and Ribary, 1993; Steriade et al., 1996). Neuromodulator levels also differ between these two brain states: during NREM sleep, acetylcholine levels in the brain stem, forebrain, and hippocampus are at a physiological nadir (Hobson et al., 1975; Marrosu et al., 1995), while cholinergic modulation during REM sleep increases to levels just below that of wake in the neocortex and even exceeds wake levels in the hippocampus (Hasselmo, 1999). In contrast, while aminergic (i.e., serotonergic and noradrenergic) neurons fire at reduced rates during NREM sleep compared to wake (Aston-Jones and Bloom, 1981), they are almost completely silenced during REM sleep (Pace-Schott and Hobson, 2002). Besides the occurrence of REMs, REM sleep is also identified by a significant reduction in muscular tone. This atonia of the skeletal musculature is a vital characteristic of REM sleep, the loss of which results in dream enactment (McCarter et al., 2012). Furthermore, while dreams can occur during all sleep stages, those of REM sleep tend to have a comparatively bizarre, emotional, and vivid quality (Suzuki et al., 2004).

In humans, NREM sleep is divided into light sleep and slow-wave (or deep) sleep (Iber et al., 2007), while in rodents all NREM sleep stages are collectively referred to as NREM or slow-wave sleep (SWS; van Twyver, 1969; Genzel et al., 2014; Oyanedel et al., 2014), with only few studies differentiating between light and deep NREM sleep (e.g., Benedetto et al., 2013), and in some cases including a spindle-rich transition to REM sleep (TR) phase (e.g., Watts et al., 2012) which is not reported in the human literature. In rodents and humans, the proportion of SWS in a given sleep cycle decreases with diminishing sleep pressure (Borbély and Achermann, 1999; Yasenkov and Deboer, 2012). In human nocturnal sleep, SWS predominates during the first half of the night while REM sleep—regulated by circadian factors—displays an inverse relationship with SWS, becoming increasingly prevalent toward the morning (Wurts and Edgar, 2000). In rodents, REM sleep does not appear to follow a circadian rhythm (Yasenkov and Deboer, 2012) and takes up a higher proportion of overall sleep compared to humans (Mendelson and Bergmann, 1999).

NREM Sleep and Memory Consolidation

The idea that sleep is important in the consolidation and processing of both recent and remote memories is well established (for an extensive review, see Rasch and Born, 2013). Based on early rodent work this memory function of sleep was primarily ascribed to REM sleep. However, more recent work in both rodents and humans strongly supports a role of NREM sleep in memory reactivation and consolidation (Stickgold, 2005; Girardeau et al., 2009; Diekelmann and Born, 2010; Ego-Stengel and Wilson, 2010; Rasch and Born, 2013). The high frequency thalamocortical spindles and associated hippocampal sharp-wave ripples, which occur during both stage 2 NREM and SWS (Genzel et al., 2014), are thought to reflect processes underlying synaptic plasticity (Steriade, 1999; Sejnowski and Destexhe, 2000). The low levels of acetylcholine during NREM sleep disinhibit communication between the hippocampus and neocortex (Hasselmo, 1999). This, in conjunction with the high amplitude slow waves of SWS is thought to drive the transfer of declarative memory traces from the hippocampus to the neocortex (Rasch and Born, 2013) by providing windows of wide-spread depolarization during which higher frequency activity (including spindles) is synchronized across various brain regions (Battaglia et al., 2004; Compte et al., 2008; Mölle and Born, 2009, 2011). In support of this, overnight improvement in memory performance is predicted by the amplitude of slow waves in both rats and humans (Marshall et al., 2004; Heib et al., 2013; Binder et al., 2014), as well as the occurrence of spindle activity during the up-phases of slow oscillations in humans (Mölle et al., 2011; Cox et al., 2012; Ngo et al., 2013). Similarly, the duration of stage 2 NREM sleep predicts overnight consolidation of both declarative and motor memories (Walker et al., 2002; Fogel and Smith, 2006; Ruch et al., 2012). Studies investigating the function of REM sleep have been comparatively unfruitful—often yielding conflicting results, thus leading to an overall neglect of this sleep stage. There is however considerable evidence linking REM sleep with the processing of emotional memories, discussed in the following section. A separate line of research implicates REM sleep in the consolidation of procedural skills, the mechanism of which deserves consideration; however this exceeds the scope of this review.

REM Sleep and Emotional Memory

Events that elicit an emotional response tend to be remembered more reliably and more long-term than comparatively unemotional events (LaBar and Cabeza, 2006). Emotional responses are most commonly elicited by situations relevant to survival. Although emotions are undoubtedly important in guiding immediate behavior—whether by triggering a fight or flight response, driving reproduction or seeking nourishment—retaining memory of the experience that elicited the emotion carries the additional benefit of guiding future behavior in similar situations, and thus would improve overall chances of survival (Hamann, 2001). The neural mechanism underlying the influence of emotion on long-term memory retention involves co-activation of the hippocampus and the amygdala—the emotional center of the brain. The amygdala appears to modulate hippocampal activity, thus facilitating the preferential encoding of emotional memories and potentially their tagging for future consolidation.

Several studies support the central role of the amygdala in mediating the prioritized consolidation of emotional vs. neutral memories. Bilateral amygdala damage selectively impairs emotional memory (Adolphs et al., 1997). In a separate study, the degree of left hippocampal damage was found to negatively predict emotional memory performance (Richardson et al., 2004). More strikingly, amygdala activity during memory encoding predicted later recall of negative (Cahill et al., 1996) and positive (though not neutral) memories (Hamann et al., 1999). Furthermore, using event-related fMRI, Dolcos et al. (2004) showed that the interaction of activity between the amygdala and hippocampus predicted recall of emotional vs. neutral memories.

In rodents, memory tasks tend to be inherently emotional. Often the emotional response represents the actual memory (e.g., in fear conditioning or extinction), or else it is used as an incentive to perform a memory task (e.g., a food reward or the avoidance of pain). Similarly to the work in humans, there is a large body of evidence supporting a role of amygdala activity in emotional memory (i.e., fear conditioning) in rodents (for a review, see LeDoux, 2003). Though—due to the lack of an adequate non-emotional control—the role of the amygdala in more indirect forms of emotional memory in rodents is less clear.

Sleep appears to facilitate the preferential consolidation of emotional memories. Though there is evidence supporting a role of SWS in this process (Groch et al., 2011; Cairney et al., 2014), a larger body or research implicates REM sleep in both the selective strengthening of emotional memories as well as the modulation of the emotional response associated with specific stimuli. This dual-process is described in the "sleep to forget sleep to remember" (SFSR) hypothesis proposed by Walker (2009). Evidence for the role of REM sleep in emotional memory processing is summarized in the following two sections.

Behavioral Evidence

Early studies on REM sleep examined the effects of REM sleep deprivation (REMSD) on memory consolidation and encoding in rodents. Post-training REMSD was consistently found to impair avoidance learning (Pearlman, 1969; Leconte and Bloch, 1970; Fishbein, 1971; Smith and Kelly, 1988), avoidance conditioning (Leconte and Bloch, 1970), and fear conditioning (Menz et al., 2013). Conversely, REMSD preceding training impeded the efficiency of fear conditioning (McGrath and Cohen, 1978; Smith, 1985; Bueno et al., 1994) and avoidance learning (Hartmann and Stern, 1972; Sagales and Domino, 1973; Danguir and Nicolaidis, 1976). Fear extinction was also impaired following REMSD compared to uninhibited sleep in rats (Silvestri, 2005; Fu et al., 2007). However, it appears the effects of REMSD are only short-lived, not persisting beyond recovery sleep (Fishbein, 1971). Furthermore, the deleterious effects of REMSD are likely to be explained by the extreme stress resulting from the so-called flowerpot method used to prevent REM sleep (Horne and McGrath, 1984). This method typically involves placing the animal on a small platform above water so that when REM sleep associated muscle atonia sets in, the animal slips into the water and awakens.

A recent study using REMSD provides more striking evidence for a role of REM sleep in emotional memory processing: Ravassard et al. (2015a) trained rats in contextual fear conditioning followed by short-term and non-stressful REMSD. They found that 4 h of REMSD impaired both the consolidation of contextual fear conditioning and long-term potentiation (LTP) within the CA1 region of the hippocampus. Conversely, rodents that obtained a comparably higher amount of REM sleep following contextual fear conditioning displayed stronger consolidation, as well as greater hippocampal LTP. Furthermore, both measures were positively correlated with REM sleep amount. This fits with further evidence showing that increasing REM sleep duration in rats—through either carbachol (an acetylcholine agonist) or through REMSD-induced REM sleep rebound—led to enhanced memory retention of a reward-memory based Y-maze task across sleep (Wetzel et al., 2003)—suggesting REM sleep may also benefit positive emotional memory processing.

In humans, sleep in general has been shown to benefit fear extinction (Pace-Schott et al., 2009; Kleim et al., 2014). The amount of REM sleep obtained following fear extinction was shown to predict a decrease in autonomic arousal based on skin conductance (Spoormaker et al., 2010). Conversely, disrupting sleep through repeated awakening only impaired extinction if awakenings occurred during REM sleep, but not if they occurred during NREM sleep (Spoormaker et al., 2012). In addition to supporting fear extinction, REM sleep was found to predict post-sleep recognition of negative emotional pictures (Nishida et al., 2009; Groch et al., 2013), negative and positive emotional faces (Wagner et al., 2007) as well as recall of emotional texts (Wagner et al., 2001) compared to neutral controls. Administration of hydrocortisone during sleep following an emotional memory task resulted in superior recognition for emotional vs. neutral images (van Marle et al., 2013). Although sleep was not recorded in this study, the observed strengthening of emotional memory could be related to cortisol-mediated processes during REM sleep, as cortisol levels are naturally elevated during REM compared to NREM sleep (Steiger, 2007).

Physiological Evidence

Physiological evidence also supports a role of REM sleep in memory. Areas implicated in memory processing during wake, in particular limbic circuits within the medial temporal lobe, are highly active during REM sleep (Maquet et al., 1996; Braun, 1997; Nofzinger et al., 1997; Braun et al., 1998; Nir and Tononi, 2010). At a cellular level, Pavlides and Winson (1989) observed reactivations of hippocampal neurons active during prior wakefulness during subsequent REM sleep. Even at a molecular level—plasticity-related gene expression increases within the hippocampus during REM sleep (Ribeiro et al., 1999). A recent study from the same group compared mRNA levels of plasticity-related genes within the hippocampus following either exposure to a novel or familiar control environment (Calais et al., 2015). The rats were killed either after 30 min of stable wake, SWS or REM sleep. mRNA expression of several plasticity-related genes were significantly upregulated during REM sleep following exposure to a novel environment—though not during post-training SWS or wake. There was also no upregulation of plasticity-related gene expression in rats who had not been exposed to the novel environment. A further recent study also revealed that increasing REM sleep amount through REMSD-induced rebound up-regulated the expression of plasticity-related transcription factors within the hippocampus (Ravassard et al., 2015b).

A distinct role for REM sleep in memory is also supported by the striking similarities and contrasts between neuromodulator states in REM sleep and wakefulness. The wake-like levels of acetylcholine in the limbic system suppress excitatory feedback potentials within the hippocampus and in the cortex (Hasselmo and Bower, 1993). During wake, this is thought to promote memory encoding by allowing the formation of new memory traces within the hippocampus without interference from previously stored memory traces (Hasselmo, 2006). Noradrenaline has been shown to suppress excitatory feedback transmission within the somatosensory and piriform cortex (Dodt et al., 1991; Hasselmo et al., 1997; Hasselmo, 1999), but not the hippocampus (Mueller et al., 1981). While wake is characterized by both high acetylcholine and noradrenaline levels, in REM sleep only acetylcholine is raised. As a consequence, excitatory feedback within the neocortex would remain uninhibited during REM sleep (Hasselmo, 1999), while hippocampal afferent inputs would be suppressed (Marrosu et al., 1995).

Based on these neuromodulator states, it has been proposed that during REM sleep, memories within the neocortex—free from interference from the hippocampus—recombine and potentially integrate into existing memory networks between periods of NREM sleep-dependent memory consolidation (Hasselmo, 1999; Walker, 2009; Walker and Stickgold, 2010; Sterpenich et al., 2014). It is important to stress that most of these observations are performed on cortical/hippocampal slices, thus the relationships inferred in terms of cortical-hippocampal interaction are very tentative.

REM Sleep, an Emotional Brain State?

Rapid-eye movement sleep possesses a unique physiology which appears particularly amenable to the processing of emotional memories (Paré et al., 2002; Hu et al., 2006). Functional neuroimaging studies reveal significantly increased activation in the amygdala, striatum, hippocampus, medial prefrontal cortex and insula, which are areas strongly associated with emotional processing in wake (Nofzinger, 2005; Miyauchi et al., 2009; Dang-Vu et al., 2010). The heightened activity within the limbic system in particular (Maquet et al., 1996; Wehrle et al., 2007; Miyauchi et al., 2009) alludes to the established link between limbic activation during emotional memory encoding and future recall (Cahill, 2000; McGaugh, 2004). Possibly as a consequence of its emotional physiology, REM sleep is unique for its comparably emotional dreams (Hobson et al., 2000) which often contain elements of the dreamer's recent memories (Nielsen and Powell, 1992; van Rijn et al., 2015).

REM Sleep and Emotional Arousal

In addition to a general role of REM sleep in emotional memory processing, a separate line of research has emerged concentrating on a more specific link between REM sleep and the modulation of emotional responses. Whether this role is part of the same mechanism, or relies on distinct processes is unclear and needs to be investigated more systematically. This section reviews evidence specifically linking emotional response modulation and REM sleep.

The Co-Morbidity of REM Sleep and Mood Disorders

Though many psychological disorders are comorbid with sleep disorders, it is particularly of note that mood disorders tend to be associated with unusual REM sleep: in depression, REM sleep is pathologically increased (Tsuno et al., 2005; Armitage, 2007; Gottesmann and Gottesman, 2007); a hallmark of post-traumatic stress disorder (PTSD) is the occurrence of flashbacks during REM sleep—often resulting in dream enactment and distressing awakenings (Mellman et al., 2007); while in patients suffering from anxiety, REM sleep percentage and REM density during REM sleep tend to be reduced (Rosa et al., 1983; Fuller et al., 1997). Thus pathological REM sleep may underlie some of the symptoms of mood disorders (Walker and van der Helm, 2009). Even in mice models for depression (i.e., stress vulnerable or chronically stressed strains), REM sleep appears to be disinhibited (Kimura et al., 2014), suggesting that REM sleep is related to emotional processing in both humans and rodents.

Experimental Evidence for a Role of REM Sleep in Emotional Regulation

Some evidence suggests a sleep-dependent decrease in both subjective emotional arousal and autonomic response to negative stimuli compared to an equally long period of wake in humans (Gujar et al., 2011; van der Helm et al., 2011). In line with this notion, sleep-dependent habituation was only observed across naps containing REM sleep, not across naps consisting solely of NREM sleep (Gujar et al., 2011).

In contrast, Groch et al. (2013) found that subjective ratings of arousal to negative images was preserved over both SWS-rich early and REM sleep-rich late night sleep using a split-night design. In a further study, participants rated emotional stimuli as more negative across late sleep compared to early sleep (Wagner et al., 2002). Similarly, subjective emotional arousal went down across wake and was maintained across sleep (Baran et al., 2012). The degree of arousal maintenance was associated with greater time spent in REM sleep. REM sleep amount also predicted an increase in autonomic response in the form of skin conductance to emotional images shown before and after sleep (Baran et al., 2012). Furthermore, REMSD reduced arousal ratings to negative images presented before and after sleep (Lara-Carrasco et al., 2009). Thus it appears that REM sleep may modulate emotional arousal, however the direction of this change may depend on other yet to be determined factors, such as the nature of the emotional stimuli, the stress experienced during the task or possibly the involvement of memory (Genzel et al., 2015).

Theta Activity

Theta activity describes synchronized oscillating local field potentials of neuronal populations within the range of 4–10 Hz initially observed in rodents (Siapas et al., 2005). It is considered a characteristic of hippocampal activity during both active exploratory behavior and REM sleep (Winson, 1974; Kemp and Kaada, 1975; Buzsáki, 2002). Rodents also display theta activity within the amygdala and ventromedial prefrontal cortex (Sörman et al., 2011; Brankačk et al., 2012)—areas strongly associated with cognitive and affective functions (Siapas et al., 2005; Sigurdsson et al., 2010). Furthermore, theta activity can be synchronized across disparate brain regions in wake (O'Neill et al., 2013) and REM sleep (Popa et al., 2010). Although humans also display a distinct 4–10 Hz hippocampal activity during both active wake (Burgess and Gruzelier, 1997; Ekstrom et al., 2005; Lega et al., 2012) and during REM sleep (Cantero et al., 2003) which is also observed in the neocortex (Cape et al., 2000; Nishida et al., 2009), this activity does not appear to be synchronized between the hippocampus and neocortex (Cantero et al., 2003; Axmacher et al., 2008). Instead, a slower ~3 Hz delta range activity—referred to as either rhythmic slow activity (RSA) or slow theta—has been proposed to be more physiologically analogous to rodent theta activity (Moroni et al., 2007; Lega et al., 2012). Similarly to the theta activity observed in rodents, human slow theta (hence forward referred to simply as theta activity) also occurs in the human hippocampus during both wake and REM sleep (Moroni et al., 2007; Lega et al., 2012). The possible explanation for humans having a slower version of theta activity is the larger brain size which may require slower oscillations to travel greater distances between brain regions (Moroni et al., 2007). Accordingly, a slower hippocampal theta activity is also seen in dogs, cats, and monkeys (Lega et al., 2012).

Theta Generation and the Role of Acetylcholine in Rats

Hippocampal theta activity appears to originate from nuclei within the brain stem which project via the hypothalamus to the septal complex comprising of the medial septum and a subregion of the Broca area (Pignatelli et al., 2012). The septal complex, in turn, projects to the hippocampus via the fimbria-fornix pathway. The medial septum contains pacemaker cells which fire at theta frequency (Dragoi et al., 1999). Some of these pacemaker cells release acetylcholine (Mesulam et al., 1983) and GABA (Freund, 1989). Inhibiting medial septum cell activity though targeted injection of lidocaine (Winson, 1978) or muscimol (Bland et al., 1996) leads to the complete suppression of hippocampal theta oscillations. Both acetylcholine and GABA jointly contribute to generating theta, as reductions of either leads to partial but not complete abolishment of theta power (Yoder and Pang, 2005; Li et al., 2007).

Given the strong link between acetylcholine and theta activity, the role of acetylcholine in memory processes within the hippocampus is highly indicative of the function of theta activity. It appears that high levels of acetylcholine enhance memory encoding during wakefulness, yet do not affect retrieval in a range of learning tasks in both rats and humans (for a review, see Hasselmo, 2006). Early work in rats showed that blocking acetylcholine through muscarinic antagonists (such as scopolamine) disrupted memory encoding if the drug was administered prior to learning, as opposed to during the gap between learning and recall (Ghoneim and Mewaldt, 1975, 1977). In humans scopolamine also disrupted encoding of memories without affecting retrieval (Atri et al., 2004; Hasselmo and McGaughy, 2004). Thus it appears acetylcholine is only involved in the encoding though not the consolidation of novel hippocampal memory traces during wake.

This has enticing implications for investigating the function of REM sleep, during which hippocampal acetylcholine levels exceed those of wake. This would suggest encoding-related processes occur during REM sleep—in stark contrast to the acetylcholine-independent memory consolidation processes occurring during NREM sleep.

The Role of Wake Theta in Memory

Hippocampal theta activity during wake has been associated with memory formation and function in a number of species (Dragoi and Buzsáki, 2006; Montgomery et al., 2008; Mizuseki et al., 2009). The specific role of theta activity in this is thought to be the binding of disparate brain regions during encoding and retrieval (Vertes, 2005).

Physiological evidence strongly supports a role of hippocampal theta activity in rats in the formation of novel memories during wake. Thus seminal *in vitro* work by Huerta and Lisman (1995) demonstrated that a priming pulse (four pulses delivered at 100 Hz) induces LTP in the hippocampal CA1 of a brain slice only if the pulse arrives at the peak of carbachol-induced theta activity (defined by the authors as 5–12 Hz). Conversely, pulses delivered at the negative peak of theta activity resulted in long-term depression (Huerta and Lisman, 1995; Hölscher et al., 1997). This observation, initially made in hippocampal slices, has been subsequently confirmed in wake behaving animals by stimulating at peaks/troughs of theta in the perforant path (Orr et al., 2001) and in CA1 (Hyman et al., 2003).

Electroencephalographic current source density data has shown that subregions of the rat hippocampus are out of phase with respect to theta activity (Buzsáki et al., 1986; Brankačk et al., 1993). Specifically, theta activity within the entorhinal cortex is 90°out of phase with that of CA3, and is in phase with that of CA1 cortex (Mizuseki et al., 2009). Taken together, this suggests both spatially and temporally differential theta-driven plasticity within the hippocampus.

Behavioral evidence in rats also supports a role of hippocampal theta activity during wake in memory encoding. Thus hippocampal theta power during encoding predicts the success of later recall (Berry and Thompson, 1978; Seager et al., 2002; Nokia et al., 2008), while disrupting theta activity pharmacologically—or through lesioning areas implicated in theta generation—significantly impairs learning (Winson, 1978; Givens and Olton, 1990). It appears not only the presence, but also the timing of learning with relation to theta is important in determining the success of encoding. Thus, the rate of learning in rabbits is fastest when hippocampal theta power is at its peak (Berry and Thompson, 1978). Also in rabbits, the rate of conditioning to a stimulus is increased in both delay (Seager et al., 2002) and trace conditioning (Griffin et al., 2004) when the stimulus is timed to appear during bouts/periods of the theta rhythm.

Human studies are comparatively scarce, given that hippocampal theta activity can only be recorded intracranially in epileptic patients. Whereas neocortical theta range (4–8 Hz) activity reliably predicts encoding, working memory and navigation (for a review, see Kahana et al., 2001), the link between hippocampal theta activity and memory appears to be more complex than that observed in rodents. Lega et al. (2012) were the first to systematically analyze hippocampal electroencephalography in humans during episodic memory encoding and retrieval. They reported peak activity around 3 and 8 Hz within the hippocampus. While the power of 3 Hz activity increased during successful encoding trials, 8 Hz activity displayed an inverse relationship. Furthermore, 3 Hz power was correlated with hippocampal gamma power. From this, the authors concluded that delta range 3 Hz activity within the hippocampus—similarly to the slower theta observed in humans during REM sleep—is the human analog to rodent hippocampal encoding-related theta activity. Both frequencies were synchronized between the hippocampus and the temporal cortex, suggesting hippocampal-cortical communication. Somewhat different results were reported by Rutishauser et al. (2010), who found that performance in a visual recognition task was predicted by spike coherence with ongoing hippocampal activity at an average of 5 Hz, though—similar to Lega et al. (2012)—this coherence peaked at 3 Hz.

Taken together, there is strong evidence supporting a role of theta activity during wake in the modulation of hippocampal plasticity which is clearly indicative of successful encoding/recall in behavior in both rodents and humans. The following section will highlight the similarities and differences between wake and REM sleep theta activity.

Wake vs. REM Sleep Theta

Both wake and REM sleep theta share a similar frequency range and distribution throughout the brain in rodents and humans. Theta activity in both states is associated with the burst-like discharge of acetylcholine—which is strongly linked with plasticity—within the basal forebrain (Lee et al., 2005). There is however some evidence that wake and REM sleep theta differ in their generation and function. Firstly, a genetic mutation in mice was found to slow down hippocampal theta frequency (defined as 5–9 Hz) in REM sleep, but not in wake (Tafti et al., 2003). A further study found that coupling between theta and gamma activity within the parietal cortex of mice is greater in REM sleep compared to wake (Scheffzük et al., 2011). This particularly applies to the coupling between theta and fast gamma (120–160 Hz), which is ninefold stronger in REM vs. wake. Taken together, this suggests that—at least in rodents—wake and REM sleep theta differ in either their generation mechanism or regulation and may serve distinct, though possibly related functions.

REM Sleep Theta and Gamma Coupling

Rapid-eye movement sleep theta activity appears to also modulate higher frequency activity in the brain. Thus, theta–gamma phase coupling during REM sleep within the hippocampal CA1 region in rats was found to be distinct for slow, mid-frequency and fast gamma (Belluscio et al., 2012). Gamma amplitude within these three bands was found to be modulated by theta phase. Phase-phase coupling was only detected between theta and slow and mid-frequency gamma, though not between theta and fast gamma. The authors interpreted this finding as suggesting an intricate multiple time-scale control of neuronal spikes during REM sleep, supporting information transfer and spike timing-dependent plasticity. Gamma oscillations nested within theta cycles have been proposed to allow the short term working memory of 7 ± 2 items in a list, as this number corresponds to the number of sub-cycles of gamma nested within one theta cycle (Lisman and Idiart, 1995). Therefore as different bands of gamma are coupled differentially to the phases of theta between wake and REM; REM sleep could effectively represent a reweighting of the items which are stored during wakefulness.

Hippocampal Temporal Coding and Sequential Activity

A prominent feature of the hippocampus is the presence of neurons which fire in particular locations, with an ensemble forming a map of space when a rat navigates in the environment; these are termed place cells (O'Keefe and Dostrovsky, 1971). These cells have been found across several species including humans (Ekstrom et al., 2003). The spatial firing of these neurons is modulated by the environmental geometry (O'Keefe and Burgess, 1999), context (Anderson and Jeffery, 2003), and time/distance traveled (Pastalkova et al., 2008; MacDonald et al., 2011). This multi-faceted representation has led to the suggestion that they encode episodes structured in space or episodic memory on the single neuron level.

During wake, place cells are coordinated with the ongoing theta oscillation such that a place cell spikes at subsequently earlier phases of theta as the rat travels through the firing field of the cell (O'Keefe and Recce, 1993). Including and excluding spatially modulated cells, distinct classes of cells within the hippocampal formation (i.e., pyramidal, interneurons, and granule) fire on average at particular phases of theta (Skaggs and McNaughton, 1996). Skaggs and McNaughton (1996) noted that certain place cell firing within a theta cycle should reflect the order in which the cells' place fields are arranged in space, thus giving rise the temporal encoding of traversed space over a theta cycle. Furthermore individual cells in the hippocampus fire at different phases of theta in novel vs. familiar environments in wake (Lever et al., 2010) and in REM sleep (Poe et al., 2000). Hasselmo (1999) proposed this phasic difference can act as a switch between encoding and retrieval of memories during wake. In REM sleep however, such a phase shift of cell firing could prioritize novel or emotionally salient memories while offloading the hippocampus of memories with less novelty or emotional salience. A possible indicator of such reorganization is provided in the work of Grosmark et al. (2012)—where a change in excitability is seen in the form of greater synchrony and decreased firing rate variability in the hippocampus following REM sleep with high theta power.

A specific phenomenon—initially termed replay—identified the re-activation of place cell sequences in a temporal order strikingly similar to that observed during previous experience (Dragoi and Buzsáki, 2006; Foster and Wilson, 2007; Gupta et al., 2012; O'Neill et al., 2010). This temporally coordinated firing of place cells takes place at a 20-fold faster rate than experienced during traversal of the environment. These events occur in both quiet wake (Foster and Wilson, 2006; Jackson et al., 2006; Diba and Buzsáki, 2007), and SWS—in both states these replay events are associated with the occurrence of hippocampal sharp-wave-ripples (SWRs; Wilson and McNaughton, 1994; Skaggs and McNaughton, 1996; Nadasdy et al., 1999; Lee and Wilson, 2002).

Temporally coordinated activity of place cells preceding experience in a novel unexplored environment (Dragoi and Tonegawa, 2011) has also been demonstrated, this phenomenon occurs before experience of the environment and therefore could underlie prospective planning by rehearsing and strengthening possible future trajectories.

Pertinent to our discussion, these sequences could also encode emotional salience, as reactivations leading to remembered goal (reward) locations appear to be preferentially activated during wake SWRs (Pfeiffer and Foster, 2013). Sequences associated with previously unexplored rewarded vs. unrewarded goal locations are also preferentially activated during prior SWS (Ólafsdóttir et al., 2015).

Critically, coordinated sequential activity of hippocampal place cells also occurs during REM sleep (Louie and Wilson, 2001) and thus in the presence of theta and absence of SWRs. Reactivations in REM sleep occur at the same timescale as wake—unlike the ∼20-fold increases seen in SWS. Interestingly, REM sleep appeared to only reactivate sequences previously activated during exploration of a familiar track, though not sequences associated with a novel environment. Although the sample sessions of REM sleep analyzed were few (15 REM episodes); this could be due to lower quality post-behavioral sleep following novelty. Similarly, recent evidence revealed coordinated sequential activity amongst head-direction cells (another spatial cell which fires when the animal's head faces a particular allocentric direction) during REM sleep following wake experience also at a similar timescale to awake (Peyrache et al., 2015). These pieces of evidence clearly implicate the role of REM sleep in recapitulating wake experiences in terms of the sequential firing of individual neurons.

Though there are no human studies investigating sequential reactivation of place cells during REM sleep, the phenomenon of cued-memory reactivation during sleep (both during SWS and REM sleep) supports the idea that memories are reactivated during both sleep stages. Thus, sound cues associated with Morse code presented during REM sleep resulted in improved performance following sleep, though only if cueing occurred during phasic—not tonic (the distinction is elaborated further on)—REM sleep (Guerrien et al., 1989). In a separate study, participants were exposed to a loud ticking alarm clock while learning a set of complex rules (Smith and Weeden, 1990). Exposure to the same sound during following REM sleep led to a significant improvement in performance at a 1 week follow-up test compared to a non-cued group.

Sequential reactivations of cell assemblies representing experienced space are a clear candidate for stored memories. The fact that these occur during REM sleep – in coordination with ongoing theta activity – and that these reactivations are biased by exposure to memory cues during REM sleep – provides a strong case for REM sleep having a role in the processing of these memories.

REM Sleep Theta and PGO Waves

Rapid-eye movement sleep theta activity appears to share a common generation mechanism with other prominent REM sleep features. Thus, the generation of REM sleep theta, REMs, REM sleep atonia and pontine-geniculo-occipital (PGO) waves all depend on the ventral part of the oral pontine reticular nucleus (vRPO; Reinoso-Suárez et al., 2001). PGO waves are large (250 mV) field potentials which propagate from the pontine tegmentum, to the lateral geniculate nuclei of the thalamus and the occipital cortex (Nelson et al., 1983; Callaway et al., 1987). PGO waves during REM sleep in rodents have been repeatedly linked with emotional memory consolidation. While suppressing PGO wave generation in rats impaired avoidance memory retention across sleep (Mavanji et al., 2004), artificially enhancing PGO waves through injecting carbachol prevented deficits in avoidance memory across a period of REMSD (Datta et al., 2004). It appears the quality of PGO wave activity is directly related to memory processes, thus a number of studies have reported an increase in PGO wave density following fear memory training in rats which predicted overnight strengthening of the memory (Datta, 2000; Datta and Saha, 2005; Ulloor and Datta, 2005; Datta et al., 2008). Additionally, the success of fear extinction was recently shown to be predicted by PGO wave quality during REM sleep (Datta and O'Malley, 2013). Furthermore, post-training PGO wave density was associated with increased activity of brain-derived neurotrophic factors and plasticity-related immediate early genes in the dorsal hippocampus (Ulloor and Datta, 2005; Datta et al., 2008). Selective elimination of PGO wave generating cells prevented these increases, while enhancing PGO waves through cholinergic activation of these cells augmented the increases. Thus, it has been proposed that PGO waves enhance synaptic plasticity in areas they pass through (Datta et al., 2011), which includes the hippocampus and amygdala (Datta et al., 1998).

Besides having an overlapping generation mechanism, PGO waves and REMs tend to be phase-locked to theta waves (Karashima et al., 2001, 2004, 2007). It appears both are driven by theta oscillations. Thus, eliciting theta activity in REM sleep through electrical stimulation applied to the medial septum in rats, entrains PGO waves and REMs to theta (Reinoso-Suárez et al., 2001). Conversely, when PGO waves are elicited through audio stimulation, theta phase is not reset, though PGO waves eventually become phase locked with theta again (Karashima et al., 2002). In a further study, Karashima et al. (2004) reported a positive correlation between both peak frequency and amplitude of hippocampal theta oscillations with PGO wave and REM density in rats. The same group also found that in both cats and rats, theta frequency accelerates several 100 ms prior to the negative peak of PGO waves (Karashima et al., 2005). When PGO waves are inhibited by lesions to the subcoeruleus region, where PGO waves are generated, synchronization between regional theta waves is disrupted. Critically, PGO wave density also reflects theta synchronization between the hippocampus and amygdala during REM sleep in rats (Karashima et al., 2010).

Though readily detectible in rats and cats, scalp EEG does not suffice in revealing PGO activity in humans. However, based on fMRI evidence, the pontine tegmentum, thalamus, primary visual cortex, putamen, and limbic areas activate in synchrony with the occurrence of REMs, which strongly suggests a similar activity in humans (Wehrle et al., 2007; Miyauchi et al., 2009). Due to the common generation mechanism of REMs and PGO waves, REM density is a commonly used measure for REM sleep intensity in humans. REM density has been observed to increase following stressful periods of learning—based on University students during an exam preparation (Smith and Lapp, 1991). This could reflect the enhanced processing of emotional memories (i.e., exam material paired with the fear of failing an exam) during REM sleep.

Taken together, it appears that in rodents, theta activity during REM sleep—and specifically the theta synchronization between the amygdala and hippocampus—drive large scale synchronized activation in the form of PGO waves, which in turn enhance synaptic plasticity within the hippocampus and amygdala. This, in combination with the evidence linking PGO wave density with emotional memory processing, strongly supports a specific role of REM sleep theta activity in the selective processing of emotional memories. It is possible that a similar relationship between theta coherence within the limbic system and PGO waves exists in humans, however evidence for this is lacking.

The Role of REM Sleep Theta in Emotional Memory

In addition to evidence linking the occurrence of REM sleep with emotional memory consolidation, there is some evidence directly linking REM sleep theta with emotional memory processing. Following training in an avoidance task, compared to a preceding control night, rats displayed an increased amount of REM sleep periods 17–20 h following training, as well as increased theta power during these REM sleep periods (Fogel et al., 2009). Interestingly, sleep spindle activity during SWS was also enhanced, supporting the notion that the two sleep stages serve complimentary roles in fear memory processing. In a study by Hegde et al. (2011) REM sleep duration in rats was also increased during the recovery period following several days of chronic stress immobilization. The authors also found a decrease in theta coordination between the hippocampus and lateral amygdala which was negatively correlated with REM sleep duration.

A more compelling link between REM sleep theta and fear memory consolidation was shown in a study on rats by Popa et al. (2010), which showed that theta coherence between the hippocampus, medial prefrontal cortex and amygdala predicted bidirectional changes in fear memory across sleep. These same brain areas exhibit synchronized theta activity when a rat is presented with a conditioned stimulus in wake following Pavlovian fear learning (Seidenbecher et al., 2003). This is observed for long term conditioning (24 h following fear conditioning), however not in the short term (within 2 h; Narayanan et al., 2007). This supports the notion that coherent theta activity within these areas during REM sleep is somehow involved in the long term consolidation of fear memories.

Due to the lack of an adequate non-emotional control task in rodent studies, we cannot exclude the possibility that non-emotional memory consolidation is equally dependent on REM sleep theta activity. Human studies allow a clear separation of emotional and non-emotional memories—though human intracranial studies investigating the role of hippocampal theta activity during REM sleep on emotional memory processing are limited. However, given the coherence of theta activity between the hippocampus, amygdala and neocortex in rats both during wake (Siapas et al., 2005; Lesting et al., 2011, 2013) and REM sleep (Popa et al., 2010) it is possible that a similar coherence exists in humans. Theta activity recorded from the scalp during REM sleep using EEG may therefore be indicative of hippocampal theta activity. One such EEG based study in humans found that right prefrontal REM sleep theta (4–7 Hz) power during an afternoon nap predicted superior post-nap recognition of emotionally negative vs. neutral images encoded before the nap (Nishida et al., 2009). In a wake control group, recognition of both image types did not exceed pre-nap baseline levels. In a separate study, Prehn-Kristensen et al. (2013) compared sleep-dependent emotional memory consolidation between adults, healthy children and children with ADHD. They discovered a stronger emotional benefit in healthy children compared to both other groups. Similarly to the previous study, frontal theta activity positively correlated with emotional memory performance in both adults and healthy children, however in children with ADHD, frontal theta activity negatively predicted emotional memory performance. Based on these two studies, it appears cortical theta activity during REM sleep represents some form of emotional memory processing in humans. However, intracortical evidence is needed to clarify the role of the hippocampus in this process.

REM Sleep Theta During Tonic vs. Phasic REM Sleep

Rapid-eye movement sleep itself is not a homogenous state. It is often described as either phasic or tonic—with tonic REM sleep taking up approximately 95% of REM sleep in rats (Montgomery et al., 2008). During phasic REM sleep, REMs, PGO waves and muscle twitches occur in bursts and are accompanied by an increase in vegetative activation as well as an increase in both frequency and amplitude of hippocampal theta activity (Brankačk et al., 2012). Tonic REM sleep in contrast is characterized by more evenly distributed PGO waves.

The existence of phasic REM sleep in humans is assumed based on a similar occurrence of phasic bursts of REMs accompanied by muscle twitches and cardiorespiratory irregularities (Carskadon and Dement, 2005). Interestingly, unlike in rodents in which hippocampal theta activity occurs throughout REM sleep (Brankačk et al., 2012), Cantero et al. (2003) described phasic bursts of REM sleep theta activity in humans—approximately 1 s in duration—and a lack of theta activity during tonic REM sleep. A previous study had failed to detect significant REM sleep theta activity during human REM sleep within the human hippocampus (Halgren et al., 1978; Bódizs et al., 2001), while a further study reported only a rare occurrence of theta in cortices surrounding the hippocampus (Uchida et al., 2001, 2003).

Discrepancies between these studies were ascribed to differences in recording methods, specific brain areas recorded from, and the pathology of the respective subjects (e.g., epilepsy; Bódizs et al., 2005; Tamura et al., 2013).

In rats, theta and gamma synchrony within the hippocampus are increased during phasic vs. tonic REM sleep (Montgomery et al., 2008). During tonic REM sleep, theta coherence is increased within the dentate gyrus (DG) and between the DG and CA3. Montgomery et al. (2008) suggest that the increase in DG synchrony accompanied by CA1/CA3 coherence reduction in the gamma range during tonic REM could mediate pattern separation for subsequent retrieval, which is thought to be a key function of the DG during wakefulness (Leutgeb et al., 2007; McHugh et al., 2007; Bakker et al., 2008). The heightened acetylcholine levels during REM sleep would facilitate this pattern separation by reducing interference of excitatory feedback within the hippocampus (Hasselmo, 1999), thus facilitating selective encoding.

In contrast, phasic REM sees an increase in theta and gamma coherence in DG together with an increase in gamma coherence in CA3/CA1, thus facilitating greater information exchange between the hippocampus and neocortex during REM sleep (Datta et al., 2004; Karashima et al., 2005; Montgomery et al., 2008), in which activity could be replayed to the cortex (Louie and Wilson, 2001). A separate study found greater theta synchrony within the prefrontal cortex of rats during phasic vs. tonic REM and an increased theta/gamma synchrony within the prefrontal cortex during tonic vs. phasic REM sleep (Brankačk et al., 2012). Though the significance of these findings in linking the two REM sleep states with memory is yet unclear, they support the notion that they serve separate functions.

Conclusion

Based on the evidence reviewed above, it appears that theta activity during REM sleep drives the emotionally modulated processing of novel memory traces within the hippocampus, possibly in preparation for consolidation during NREM sleep. This is supported by the observation that theta activity—in particular theta coherence between the hippocampus and amygdala—drives high-amplitude PGO waves, the density of which predicts the expression of plasticity-related genes within the hippocampus and amygdala. As amygdala-hippocampal coherence during wake predicts future recall of emotional events, it is possible that this coherence in REM sleep reflects the selective processing of emotional memory traces.

The timing of spike activity within the hippocampus with respect to theta phase is vital in determining whether long term potentiation (LTP) or depression (LTD) occurs. While hippocampal activity associated with a novel experience occurs at a similar phase during REM sleep compared to wake—thus promoting LTP—activity associated with a familiar experience occurs at a phase promoting LTD. In addition, evidence suggests theta activity during REM sleep increases unit synchrony and decreases firing rate variability. Taken together, this implies REM sleep in processes of separation and offloading of traces previously consolidated during NREM sleep, thus freeing capacity to encode and process novel memories.

In addition to emotionally modulated memory processing within the hippocampus, theta activity during REM sleep could also mediate the integration of novel memory traces within the neocortex. Acetylcholine—which reduces hippocampal interference in the neocortex—is raised during REM sleep and directly correlated with theta activity within the hippocampus. In addition to the rise in acetylcholine, noradrenaline levels are extremely low during REM sleep. As noradrenaline suppresses recurrent activation within the neocortex, this drop in noradrenaline during REM sleep could allow encoding-like processes of a more elaborate nature than wake, i.e., allowing recombination and integration of novel memory traces into pre-existing memory networks. This neocortical integration may give rise to the vivid dreaming experienced during REM sleep.

Those who refute a role of REM sleep in memory (Vertes and Eastman, 2000; Siegel, 2001) refer to the observation that many antidepressants markedly reduce REM sleep in humans without causing significant deficits in learning or memory consolidation (Vertes and Eastman, 2000). Instead, Vertes and Eastman (2000) suggest the primary function of REM sleep is to provide a period of wake-like endogenous stimulation, allowing the brain to maintain necessary levels of activity throughout sleep. By doing so, REM sleep supposedly promotes the recovery from SWS and thus prepares the brain for wakefulness. However, if this was the case, one would expect the amount of REM sleep in each sleep cycle to correlate with the respective amount of SWS. Instead, REM sleep displays an inverse relationship with SWS in humans (and remaining constant irrespective of SWS in rodents) across sleep. This suggests that the function of REM sleep may not be merely a reversal of processes in SWS, but potentially an extension of SWS-dependent processes—such as the integration of novel neocortical representation within existing memory networks.

This emotionally modulated processing of memories within the hippocampus may prioritize the consolidation of emotional memories during NREM sleep. The following integration of these novel memories could allow emotional experiences to guide future behavior in similar situations. This is backed by behavioral evidence, which associates REM sleep with the selective strengthening of emotional memories and the modulation of emotional responses. The REM sleep dependent bidirectional changes in arousal reported in the literature could also be explained by integratory processes during REM sleep: if an emotional response associated with a given experience is of no direct use to the memory itself, this may be lost in this process. In contrast, an emotional response which is integral to the memory (e.g., avoidance of a deadly animal), the emotional response may be strengthened along with the memory. Thus the main function of REM sleep may be the emotionally modulated optimization of behavior.

This proposed function of REM sleep would explain why the suppression of REM sleep does not cause noticeable cognitive deficits in patients using REM-suppressing antidepressants. If not faced with emotionally trying experiences or significant changes to the environment—which would require rapid adaptation—the patients can rely on “outdated” behavioral responses to similar situations. Therefore, we hypothesize that REM sleep suppression during early childhood development would result in more striking behavioral deficits. In addition we hypothesize that parametrically varying emotional weight in the form of rewards/punishments in behavioral tasks should change the degree of theta synchronization between limbic structures, distribution of theta-phase firing of individual cells and also manifest itself as a differential number of sequence reactivations during REM sleep. Despite behavioral evidence predominantly pointing toward a role of REM sleep in predominantly emotional memory, it remains unclear whether non-emotional memories are processed independently of REM sleep—it is possible that they are also processed during REM sleep though with a lower priority. Further, it would be interesting to consider how the previously alluded to evidence linking REM sleep and procedural memory ties in with the proposed role of REM in emotional memory processing.

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Autobiographical memory and hyperassociativity in the dreaming brain: implications for memory consolidation in sleep

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In this paper we argue that autobiographical memory (AM) activity across sleep and wake can provide insight into the nature of dreaming, and vice versa. Activated memories within the sleeping brain reflect one's personal life history (autobiography). They can appear in largely fragmentary forms and differ from conventional manifestations of episodic memory. Autobiographical memories in dreams can be sampled from non-REM as well as REM periods, which contain fewer episodic references and become more bizarre across the night. Salient fragmented memory features are activated in sleep and re-bound with fragments not necessarily emerging from the same memory, thus de-contextualizing those memories and manifesting as experiences that differ from waking conceptions. The constructive nature of autobiographical recall further encourages synthesis of these hyper-associated images into an episode via recalling and reporting dreams. We use a model of AM to account for the activation of memories in dreams as a reflection of sleep-dependent memory consolidation processes. We focus in particular on the hyperassociative nature of AM during sleep.

Keywords: autobiographical memory, dreaming, memory consolidation, sleep, continuity hypothesis, hyperassociativity

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The Context of Autobiographical Memory

Whilst memories for very specific instances are referred to as "episodic" (e.g., Tulving, 1983, 2002), memory and information for and about our own experiences more generally falls under the umbrella term of "autobiographical memory" (AM; Conway and Pleydell-Pearce, 2000; Conway, 2001, 2005, 2009; Conway and Loveday, 2015). AM is a representation of experiences (episodic memories and associated details) and information (semantic knowledge) related to the self. As such it engages all aspects of the declarative memory system (Nadel, 2008; Renoult et al., 2012). Current conceptualizations of episodic memory, which break from earlier theories (e.g., Tulving, 1983), suggest that episodic memories are detailed summary accounts of short time-period experiences, which are forgotten within 24 h unless they are consolidated during sleep and subsequently become linked to AMs (Conway, 2009). Life stories, or autobiographies, are created over time into a narrative, compiled of personally salient, emotional and everyday experiences, along with facts and knowledge about ourselves (Conway and Pleydell-Pearce, 2000). Similarly, dreams are narrative simulations of autobiographical episodes (Montangero, 2012), and it has been suggested that narratives are the "basic manner in which the brain organizes experiences" (Pace-Schott, 2013, p. 2)—hence both waking AM and sleep mentation are organized in this manner. Crucially, such narratives are not composed of precise replicas of specific (episodic) experiences from the life-course. Rather, they are constructed and changed over time, much as an author may edit a novel in order to improve its readability and clarity. We propose that AM functions comparably across sleep and wake (Horton, 2011a,b; Malinowski and Horton, 2014a).

We use this account of AM to describe and explain the construction of dreams. Furthermore we explore the processes of sleep-dependent memory consolidation with a particular emphasis on the enhancement, stabilization, and integration of AMs. In this paper we propose a model in which AM experiences are broken down into constituent fragments, reactivated "offline" during sleep, and re-combined via hyperassociativity (e.g., Llewellyn, 2013) into a novel experience. This gives rise to dreaming. We argue that these processes of sleep-dependent memory consolidation crucially rely on AM functioning, in contrast to alternative models, which do not address the multimodality of memories. We emphasize we constructive nature of AM retrieval, recognizing (i) that memories change considerably over time, and (ii) that sleep can enhance AM by breaking down and re-combining memory elements, re-activating salient features and thus consolidating them via repeated activation. As such sleep-dependent AM consolidation functions to de-contextualize information, rendering salient features more retrievable following a period of sleep. In this paper we outline each of these processes in critical detail.

We will begin by reviewing the activation of AM across sleep as well as waking periods, exploring the inclusion of AMs in dreams. We then explore the activation of AM fragments in sleep and how they are hyperassociated. Next we examine the relevance of such hyperassociativity to processes of sleep-dependent memory consolidation, and finally propose a model of AM consolidation, which dreams can usefully reflect.

Constructive Memory

The constructive and malleable nature of AM renders it notoriously error-prone. Memories for personal experiences may change over time in relation to personal goals (Conway, 2001), so to align with current conceptions of the self (Conway and Pleydell-Pearce, 2000) or as some function of decreased emotional reactivity (Walker and Skowronski, 2009; Ritchie et al., 2014). In terms of the latter, the Fading Affect Bias describes the reduction of negative emotion associated with an AM over time and has been evidenced in dreams as well as waking events (Ritchie and Skowronski, 2008). Furthermore rich, false episodic memories about one's past are easily induced (Shaw and Porter, 2015). Conway and Pleydell-Pearce (2000) argue that this fluid autobiography operates under a self-memory system, in which an executive function of current personal goals filter the retrieval of long-term knowledge and experiences about one's own life. As such, retrieving autobiographical experiences is an active process and reflects the flexibility of the cognitive systems underpinning it.

Such a dynamic view of recall is not often acknowledged, particularly in the memory consolidation literature. This is perhaps not surprising, given that exploring the changes in AM over time is resource-burdensome and methodologically challenging. Nevertheless, this fluid account of AM acknowledges involvement of both semantic (personal knowledge) and episodic systems within declarative memory (Renoult et al., 2012), and therefore may align well with more recent models of memory consolidation (see Memory Consolidation in Sleep) and reconsolidation (Alberini and Taubenfeld, 2008).

As opposed to AMs, distinctions between episodic and semantic memory systems have instead dominated experimental paradigms as they are much more easily manipulated, despite the presentation of word lists as representative of episodic experiences being low in ecological validity. Nevertheless, an understanding of the processes underlying AM construction—and consequently an understanding of the ways in which humans make sense of their own life stories and selves—relies in part upon an understanding of both episodic and semantic memory processes. (For a comparison between AMs and EMs see Conway, 2009.) The key processes are encoding, storage and retrieval. Much attention has been focused in recent years on storage as an active process of consolidation and re-consolidation, and it is this that we consider in this paper, in particular in terms of how sleep can enhance AM consolidation.

Incorporations of Memories into Dreams and the Continuity Hypothesis

One's autobiography is made up of experiences from across the lifespan also including thoughts, concerns and dreams. We argue that AM operates across all states of consciousness, with memories being accessible at times involuntarily (e.g., Berntsen, 1996). The characteristics of autobiographical recall (Conway, 2005) typify the flexible and fluid nature of memory retrieval, which is often overlooked in traditional experimental paradigms.

An extension of this view is that AM operates "offline," during sleep and all its composite stages. Indeed this reflects the "continuity hypothesis" (Hall and Nordby, 1972; Schredl and Hofmann, 2003; Domhoff, 2011; Schredl, 2012; see also Horton and Malinowski, 2011); most broadly that there is overlap between cognitive processing (amongst other things) across sleep and wake. Most notably, such overlaps can be measured by comparing various aspects of (memories for) dreams to (memories for) waking experiences. A traditional view is that dreaming, and thus dream memory, is somehow deficient in comparison to waking memory (Crick and Mitchison, 1983). However as recalling both dreams and waking memories engage the same autobiographical system, some studies have demonstrated considerable overlap in the retrievability of dreams and waking experiences (Botman and Crovitz, 1990; Kemp et al., 2003; Grenier et al., 2005; Horton and Conway, 2009; Parke and Horton, 2009; Horton, 2011a,b, 2014, see also Graveline and Wamsley, 2015). Furthermore differences between waking AMs and dreams may result from methodological challenges, rather than actual differences. That is, waking AM is not flawless or even particularly accurate, although it is often deemed to be superior in accuracy and recallability than dream memories (see Chapman and Underwood, 2000). Unfortunately direct comparisons cannot be made between dream memories and waking AMs, as the validity of systematically sampled AMs can be verified whereas memories for dreams are the closest to an actual dream experience one can sample.

Nevertheless there is a wealth of evidence showing the continuity of AM across sleep and wake in terms of content (e.g., Stickgold et al., 2000; Schredl and Hofmann, 2003; Schredl et al., 2006), and consciousness and cognition (e.g., Graveline and Wamsley, 2015; Kahan and LaBerge, 1996, 2011; Kahan et al., 1997). As such the sleeping brain can reflect one's personal life history to a similar extent as waking life processes and behaviors can. One notable method for exploring the presence of AMs during sleep involves measuring the incorporation of waking AMs into dream reports.

Three overarching mechanisms have been consistently identified to operate to determine the likelihood of a waking experience appearing in dreams: its emotionality (intensity as opposed to valence), its age (see Section "Is Dreaming a Reflection of the Processes of Sleep-Dependent Autobiographical Memory Consolidation?" on the day residue and dream-lag effects), and its personal salience. Additionally there seem to be further mechanisms that underpin the likelihood of those experiences appearing as a more holistic representation or a fragmentary one, and across different periods of sleep:

(i) Emotionality: Generally dreams are more emotional than waking memories, and this effect remains when recall bias is controlled for (Schredl and Doll, 1998; Malinowski and Horton, 2014b). This may result from the preferential incorporation of emotional AMs into dreams (Horton et al., 2011) as well as the heightened activity of the limbic system during (rapid eye movement, REM) sleep. In some cases intense and negative memories appear in dreams episodically, under conditions of post-traumatic stress (e.g., Hartmann, 1996).

(ii) In only very rare cases do truly episodic memories feature in dreams (Fosse et al., 2003; Schwartz, 2003; Malinowski and Horton, 2014a).

(iii) Self-representation: current self-images have been shown to be incorporated into dreams, reflecting the activity of the working-self (Horton et al., 2009); part of the self-memory-system model of AM functioning (Conway and Pleydell-Pearce, 2000; Conway, 2005).

(iv) More generally the number of self, semantic and episodic references vary across sleep-stage (see Foulkes et al., 1989), with each aspect appearing more fragmentarily, manifesting as increasingly bizarre, across the night (Hobson et al., 2000; Malinowski and Horton, 2014c). Concurrently the extent to which waking-life references appear in the dream in an abstract (opposing literal) way increases both across the night (Wamsley et al., 2010a), and over longer time periods (Blagrove et al., 2011b).

(v) Personally salient experiences may be preferentially incorporated (Malinowski and Horton, 2014b) and the age of these memory traces may be somewhat predictable (van Rijn et al., 2015).

The non-episodic manifestation of waking AMs into dreams has been well noted (as based on Fosse et al., 2003; Malinowski and Horton, 2014a). Fosse et al. (2003) originally noted that episodic "replay" of waking life experiences was so rare in dreams that there must exist a functional dissociation between REM dreaming and episodic memory. Rather than truly episodic experiences being "replayed," as we would experience the recollection of an episodic memory during waking, elements of AMs feature heavily in dreams (Malinowski and Horton, 2014a), and may reflect the relative attenuation of frontal systems during (all stages of) sleep. According to Malinowski and Horton (2014a) whole, intact episodic memories are not useful information, therefore they are not replayed in dreams in this manner. We propose here an alternative function of AMs appearing in a more fragmented fashion during sleep: for salient fragments to be activated in a different combination, thus consolidating those features to improve their future retrievability in any context or situation that necessitates them.

Although autobiographical elements from waking life appear in dreams, experiencing a dream is often comparable to experiencing or thinking about something in the present. That is, the ability to reality monitor, or identify that a dream is a dream as distinct from waking life perception, is attenuated (unless experiencing lucidity). The dreamer typically engages with the dream-environment from a first-person perspective, is capable of thinking (McNamara, 2000), feeling (e.g., Schredl and Doll, 1998) and a host of other sensory experiences (Horton and Conway, 2009). Consequently measuring the apparent activation of fragmentary AMs in dreams seems incongruous with the fluid experience of dreaming, which is continuous, holistic and not unlike waking consciousness. Reconciling these views involves appreciating (i) that AM fragments may not be the sole constituents of a dream, (ii) that AM fragments are bound together into holistic narrative experiences (Montangero, 2012; Pace-Schott, 2013) giving rise to a multi-sensory experience, and (iii) that some cognitive processes engaged during waking may result in the synthesis of fragmentary dream elements at the point of recalling and re-telling a dream (see Horton, 2014). Indeed many models of consciousness recognize this quality of unifying disparate cognitive mechanisms and features (e.g., Baars, 2002).

Consider the following example of a dream recorded by a participant in our study (Malinowski and Horton, 2014a). The participant dreamt that she was in a back garden (of the house she grew up in), with a man (who was a character from the TV series "Heroes" which she had been watching), and he was choosing a bottle of wine (which was an activity she herself was used to doing). She later went into the kitchen and talked to a beautiful woman (who she believed to be a happier, more stable version of herself). This dream incorporates various elements of autobiographical information, both from the past (the childhood home) and arguably the future (the woman that she would like to become). Fragments of information about characters, the setting, the conversation, *et cetera*, have been taken from waking life from across a range of time-points, and have been re-bound into a novel experience. This differs substantially from experiencing a dream in which whole waking life episodic memories feature, as that would involve the characters, settings and conversations (for instance) to play out together in exactly the same way as they had been experienced during waking (Horton and Malinowski, 2011).

There is evidence that memory de-fragmentation (Payne et al., 2008b) and re-binding (Payne et al., 2009) occurs during sleep and that autobiographical recall processes further encourage the synthesis of fragmentary dream elements upon morning awakening (Hobson and McCarley, 1977; Horton, 2014). This further emphasizes the continuity of the AM system across functioning across sleep and wake.

We next propose that the appearance of re-bound AM elements in dreams is functional: to de-contextualize the salient features, as part of a process by which information can be identified as salient (in line with Stickgold and Walker, 2013). We return to this explanation in Section "Memory Consolidation in Sleep."

Hyperassociativity and Bizarreness

We argue that the process by which AM elements are re-bound in dreams occurs as a result of the hyperassociative nature of sleeping cognition (Stickgold et al., 1999; Llewellyn, 2013). Hyperassociativity, whilst rarely explicitly defined, refers to the increased activation of weakly semantically related concepts and networks, following the activation of a specific concept or memory (Stickgold et al., 1999). It therefore concerns a form of cognitive processing and has been widely proposed to illustrate typical processing within dreaming and, specifically, REM sleep (Antrobus, 1993; Hartmann, 1996; Stickgold et al., 1999; Hobson, 2002; Cai et al., 2009; Levin and Nielsen, 2009; Walker, 2009; Walker and Stickgold, 2010; Llewellyn, 2013). Specifically, the connectivity between associations can be made between memories that would be considered loosely associated during waking. Hartmann (1996, 2010a,b) argues that the associativity between activated memories can be modeled on a continuum with focused, waking thought at one end, increased associativity during daydreaming or meditation, for instance, and loose, or hyper, associativity featuring during dreaming. Hartmann (1996) proposes that the function of dreaming hyperassociativity is to process and weave emotions into more stable networks of prior experience, and we review this view elsewhere (see Malinowski and Horton, submitted). Whilst we recognize that such emotional memory assimilation during sleep is an important function of sleeping cognition (Malinowski and Horton, submitted), we recognize that hyperassociativity contributes to the selective processing of other, emotionally-neutral memories, also.

The function of this could be to allow specific fragments of waking experiences to be selectively reproduced, perhaps played out in a novel or bizarre context, rendering them context-free and subsequently increasing their inter-relations with other, more loosely-associated memory fragments. EMs, which are by definition context bound, engage hippocampal regions. AMs, instead, can be context-free and the advantage of this over time is that previously learned information is easily retrieved in any context, facilitating accessibility. Hyperassociativity involves the activation of information via a semantic network (e.g., McClelland and Rumelhart, 1985). The activated memories may be elements of experiences and may trigger the recollection of a full EM, though this is unlikely given (i) the loose and therefore disorganized nature of hyperassociativity, (ii) the lack of frontal activity during sleep, and (iii) the typical transfer of memories from hippocampal to cortical regions during sleep (Squire and Alvarez, 1995; also see Memory Consolidation in Sleep).

As noted previously, the selective fragmentation of memory elements during sleep followed by the re-binding of memory elements give rise to a holistic experience of dreaming, despite the re-bound elements often being disparate, implausible or impossible. In one study, Montangero (2012) found that 81% of dreams contained abrupt and complete changes of dream events, concluding that dream content has a "coherent but unexpected" (p.162) nature, alluding to the disparate yet narrative structure of dreams. Such odd or novel associations result from hyperassociative processing and some authors argue that this gives rise to positive experiences of insight, creativity and problem solving either during or immediately following a dream (see Barrett, 2012, for a summary). As such the hyperassociative nature of sleeping cognition could account for the discontinuities of form, context, time or location that are often reported in dreams, more commonly referred to as "bizarreness." Indeed it has been suggested that bizarreness arises out of the joining together of disparate elements (often from waking life; e.g., Revonsuo and Tarkko, 2002; Levin and Nielsen, 2007), which is also indicative of hyperassociativity.

Potential Functions of Activated Memory Fragments

Whilst some theorists argue that the creative insight gained from the novel arrangements of familiar stimuli within dreams might be a function of dreaming, there is an additional growing consensus and body of evidence implicating the role of memory, in particular improvements in recall, in relation to sleep and dreaming. These two potential functions of dreaming may be related. Given the inextricable links between AM and dreaming, we consider the AM system to be instrumental in the selective consolidation of memory during sleep, and in the associated formation of dreams. The fragmentation of AMs during sleep and subsequent re-combination of these (in dreams) not only provides novel arrangements and potential insight, but also involves the re-activation of salient features, thus consolidating those elements. We draw on other models of fragmented memory during sleep/dreaming to inform the development of our own model.

Levin and Nielsen (2007, 2009) and Levin et al. (2010) proposed the AMPHAC/AND model of dreaming. The acronyms refer to the neural circuits involved in the activation of relevant memories, emotional in this case, and their consequential fear-extinguishing function. The model accounts for the fragmentation of AM elements and their recombination into novel permutations, as described above, though with the emphasis on playing out emotional elements in a new context so to reduce the associated negative emotion (almost always fear). This theory accounts for the bizarreness so typical of dreams, the regular emotional content of dreams (Schredl and Doll, 1998) and the reduction of emotional intensity of repeated dream sources over time (e.g., see Cartwright, 2010, for a summary; Walker and van der Helm, 2009). The theory is therefore comprehensive and strongly supported by empirical data linking emotion regulation, processing, and dreaming (see Malinowski and Horton, submitted, for a thorough review). However, there are some aspects of sleep-dependent memory processing that the model does not account for, namely the links between sleep and memory consolidation, and the activation of positive as well as negative (non-fear-based) emotions (Schredl and Doll, 1998). Thus the AMPHAC/AND model acknowledges some of the trends of memory fragmentation and re-binding that occur during sleep, but offers an explanation for this based on emotional-processing rather than broader memory activation and consolidation.

There is a great wealth of evidence implicating emotional arousal as a mediator of the sleep-memory relationship (see Malinowski and Horton, submitted, for a review). As such Levin et al. (2010) emphasis upon this variable is appropriate, Future models need to acknowledge the role of emotionality in sleep-dependent memory consolidation in healthy, as well as clinical, populations. The previously mentioned Fading Affect Bias (e.g., Ritchie et al., 2014), in which the negative affect associated with a memory fades over time, was demonstrated for dream elements (Ritchie and Skowronski, 2008), reflecting further continuity in AM over sleep and wake as well as the fragmentation of AMs in dreams. The de-coupling of AMs from their emotional context has been demonstrated elsewhere (e.g., Payne et al., 2008b) and may indicate one of at least two possible mechanisms: firstly that emotional arousal associated with an AM is a marker of its salience, thus its need for consolidation; secondly that the associated emotional arousal clouds the consolidation process, thus extracting the negative affect from the remaining AM purifies the remaining elements for subsequent processing. A possible secondary process concerns the addition of associated positive affect with an AM over time, as part of the constructive recall process, in which experiences are retrieved in line with current conceptions of the self (Conway and Pleydell-Pearce, 2000).

Whilst the fading affect bias exemplifies the continuity of AM across sleep and wake, it does not propose a specific model by which these relationships exist. We next consider a memory-based account of memory activation in sleep and dreams and bear in mind the likely mediating role of emotion.

Johnson (2005) proposed that the content of dreams reflects memory activation which serves the purpose of developing "context memory." Johnson argued that information is initially learned within a specific context and then later decontextualized. This is hypothesized to occur over the life-course, with the apparent need for more REM sleep at birth taken as being supportive of this claim. There are three main limitations to this view. Firstly context memory is defined extremely vaguely and never operationalized. Context memory may refer to relational memory or sematic-association networks that pervade other literature and cognitive models (e.g., McClelland and Rumelhart, 1985), but this is unclear. Secondly Johnson draws parallels between REM sleep and dreaming, which is a largely-redundant and out-dated idea, given the wealth of evidence that dreaming can be sampled from non-REM periods (e.g., Foulkes et al., 1989) and that REM does not always give rise to dreaming (e.g., Solms, 2000). Thirdly, whilst we might indeed initially learn of experiences in a context-dependent manner, it may not be advantageous to do so. Take for instance the experience where we cross a road and have an unnervingly close encounter with a speeding car. It would be logical to extract and consolidate the elements of that experience on the basis of future need. In that case, that vehicles (not just cars) may pose a threat to our safety. As such there is a need to retrieve this useful information and apply it to future road-crossing scenarios, i.e., by being careful and attentive of oncoming vehicles. According to Johnson's theory, the context of road-crossing could pose a general threat and that context-bound detail would be consolidated during REM sleep. However, evidence shows that emotional aspects of visual memories (scenes) can be decoupled from their broader contexts and selectively consolidated during sleep (Payne et al., 2008b). So experiences can be broken down into fragments, each perhaps evaluated on the basis of emotionality or arousal, and activated individually. This move away from episodic consolidation aligns not only with our proposals concerning the fragmentation of autobiographical, rather than episodic, experiences (see, also Malinowski and Horton, 2014a) but also broader empirical illustrations of learning showing the "R-K shift"—a move from episodic to semantic retrieval of the same learned items over time (Dewhurst et al., 2009). Furthermore sleep-dependent memory consolidation processes generally propose that memories become less episodic and more semanticized, as reflected by their decreased hippocampus-dependency over time (Nadel and Moscovitch, 1997; Marshall and Born, 2007), and that the activation of more episodic memories tends to occur during slow wave (non-REM) stages of sleep. Thus Johnson's ideas concerning context memory seem largely at odds with the evidence for sleep-dependent memory consolidation and the associated fragmentation of activated memories appearing in dreams.

To continue with the road-crossing example, we can assume that memory consolidation serves the purpose of enhancing the retrievability of important aspects of an experience. This would necessitate identifying and then extracting salient features of that experience. Subsequently this would break down the episode into smaller units, and as such de-contextualizing it. The salient features would be identified as such, either by being re-activated or being associated with arousal of some kind, forming part of the consolidation process. The result would be that consolidated memory fragments would be better integrated into pre-existing networks and being more easily retrieved in times of need. To continue with this example, the recollection that vehicles may pose a threat could be applied to other potentially threatening contexts. We therefore propose the opposite to Johnson (2005) in that functional de-contextualization and fragmentation of memory experiences leads to enhanced memory. In order to appreciate this, let's briefly review our understanding of memory consolidation during sleep, then how that may relate to dreaming.

Memory Consolidation in Sleep

Memory consolidation refers to the stabilization and integration of information into long-term memory networks (Marr, 1970). This may be measured either by an increase in performance in a memory task (enhancement) or a lack of a reduction in performance (maintenance). We focus here on consolidation at a systems-level of brain and cognition, rather than synaptic-level changes over time, as the systems level reflects the activation and engagement of different brain regions, which can provide insight into the cognitive processes involved in consolidation. The standard model of consolidation (Squire and Alvarez, 1995) proposes that memories become hippocampal-independent over time, with the time-course of this process varying depending on the complexity of the memory though ranging from hours to weeks. In contrast the multiple trace theory (Nadel and Moscovitch, 1997) emphasizes the distinct processing of different kinds of declarative memories, in that episodic memories always remain somewhat hippocampal-dependent whilst semantic memories become independent. We will briefly critique these in light of the processing of AMs here.

Our understanding of the time-course of [hippocampal–cortical] memory consolidation comes in part from cognitive neuropsychology, namely patient studies of amnesics, as well as from cognitive neuroscience and animal lesion studies. The latter show a sharper decline in temporally graded retrograde amnesia compared to humans, spanning up to weeks as opposed to years (see Frankland and Bontempi, 2005, for a brief review). According to the standard view there is coordinated activation of recent memories across hippocampal–cortical networks, which leads to a gradual strengthening of cortico-cortical connections. In turn these render all new memories independent from the hippocampus and to be gradually integrated with pre-existing cortical memories (Squire and Alvarez, 1995). A feature of this standard view is that such activation occurs by replaying the original experience in some form (Marr, 1970). The alternative, multiple trace theory, approach to systems consolidation emphasizes the different networks involved in processing episodic (and therefore detailed autobiographical) memories from semantic memory (Nadel and Moscovitch, 1997). This view draws on evidence that contextually-rich episodic and spatial information within memory almost always activates the hippocampus. Thus consolidation of these memories differs from the cortical networks involved in the retrieval of more semantic, or non-declarative, knowledge. The multiple trace theory therefore has weight in that it addresses the differences between context or experience-based memories, and knowledge, though adds a layer of complexity to understanding the processing of most AMs, which comprise both episodic and semantic elements (Renoult et al., 2012).

Whilst both accounts of systems consolidation imply that memories can be set down into relatively stable structures, it is widely acknowledged that such memories can be subject to change and refinement over time (Alberini and Taubenfeld, 2008). Indeed our comprehension of the AM system (e.g., Conway and Pleydell-Pearce, 2000) serves as a reminder that retrieved memories are rarely recalled truly episodically. Rather, fragments of information about an experience, perceptions of it and information gained since an experience will be mixed in with the original experience, leading to different kinds of memory integration and transformation, such as gist extraction and insight generation (Payne, 2010; Wamsley, 2014). In this way memories are ever-changing. This is likely true of all kinds of memories, such as procedural knowledge (learning how to drive a car for instance) in addition to autobiographical experiences, for which construction is already a well-documented feature. "Re-consolidation" refers to the processes whereby recalling a memory re-activates and slightly changes it, requiring it to be re-integrated into ever refined semantic structures (Nader, 2003). Thus the time-course of consolidation processes reflects the malleable nature of remembering. Consolidation is not instantaneous, which falls in line with this view. Rather it occurs over hours, days, weeks and perhaps even longer (see Frankland and Bontempi, 2005).

Sleep is largely seen to be the state during which most memory consolidation takes place (see Payne et al., 2008a, for a thorough review). During sleep external stimuli are not perceptible, unless salient or loud enough to rouse the sleeper. Here the brain enters a reflexive state in which thoughts and experiences are internally generated (e.g., Maquet, 2000). Thus consolidation allows for previously encoded and accessible memory traces to be activated in some form without the interference of new stimuli. Alternative theories of sleep-dependent memory consolidation such as Crick and Mitchison (1983) promote the idea of the brain requiring downtime in order to process and sort what has been perceived before, and that sleep provides the ideal environment for this to occur. However, considering sleep-dependent consolidation as an "offline" process hints at passivity, which is misleading. Rather, a current body of research highlights the selective activation and processing of salient features of memories and experiences. Identifying the kinds of memories selected for activation, and how they may be broken down into constituent parts can provide insight into the larger-scale processes of memory consolidation in the sleeping brain. In time this may lead to specific and perhaps predictable hypotheses concerning dream content, for example that dream content will reflect emotionally intense waking-life experiences (Malinowski and Horton, 2014b).

Researchers are beginning to question which specific neural circuits are strengthened during sleep, and which features of a memory are preferentially retained over time. Many researchers argue that emotional features of a memory are retained (e.g., Holland and Lewis, 2008). Others have found a more general personal salience effect (e.g., van Rijn et al., 2015). Recently sleep has been shown to enhance memory features expected to be of future relevance, with specific slow-wave sleep features (spindles and slow oscillation activity) being associated with preferential consolidation (Wilhelm et al., 2011). Similarly intended actions, or goals, are more likely to be carried out following sleep (Diekelmann et al., 2013). Taken together there appears to be at least two levels of selectivity involved: a basic level in which arousal at activation might indicate whether a memory feature is deemed sufficiently salient to warrant future processing, and a higher-level process in which some more personal method of selectivity is engaged, on the basis of individual need or assimilation into an autobiographical goal hierarchy. Further research is certainly required here, though Stickgold and Walker (2013) review and emphasize the active selectivity of consolidation processes in their "triage" theory, which acknowledges in part the higher-level processes. Lewis and Durrant (2011) propose a model of sleep-dependent consolidation of schematic information, or gist extraction. Here the activation of different memories during sleep leads to overlapping and therefore repeated activation of specific memory fragments, rendering those fragments subject to greater processing and consolidation. Whilst this view may seem contradictory to Stickgold and Walker's (2013) view in that it is much more passive, with activation frequency determining consolidation, it may account for sleep-dependent processing at a later stage than the processes of selectivity outlined in the triage theory. This could, perhaps, occur later in the course of the night's sleep.

Alternatively, both systems could operate in parallel and refer to episodic (Stickgold and Walker, 2013) and semantic (Lewis and Durrant, 2011) consolidation, respectively. We believe that memory consolidation involves both the strengthening of traces representing the episodic details of experience, and the parallel integration of information extracted from experience with previously acquired semantic knowledge. In this view, episodic experiences and semantic knowledge are simultaneously broken down for processing by the same overarching AM system. Hippocampal activity reflects the activation of unique representations of episodic experiences, while cortical activation reflects semanticized and integrated information. As AM involves the activity of both declarative memory systems, it requires the processing and consolidation of experiences episodically first and more semantically later, though some experiences always retain their episodic nature. There is evidence to suggest that emotional memories, in particular, retain such episodic features. We will re-visit this idea in Section "Is Dreaming a Reflection of the Processes of Sleep-Dependent Autobiographical Memory Consolidation?" when we consider the time-course of memory incorporation and activation in dreams.

Contributory Roles of SWS and REM

Thus far we have focused largely on sleep-dependent memory consolidation as if sleep is a homogeneous state, although we have briefly referred to slow-wave-sleep in the preferential consolidation of episodic memories and REM in more semantic memory (Foulkes et al., 1989; Rauchs et al., 2005). REM has also been heavily implicated in the processing of emotional memories (Wagner et al., 2001). The profile of sleep across a typical night shows a greater density of slow-wave activity in the first half of the night, and more REM later. This may reflect the sequence of sleep-dependent memory processing. Generally, slow wave sleep involves the reactivation of experiences from the day, then those experiences are broken down and emotional, and/or salient aspects selectively processed, during REM.

Furthermore during non-REM, there is evidence for gist-extraction and schematic representation (Lewis and Durrant, 2011; Tamminen et al., 2013), with further evidence for problem-solving and insight benefitting from sleep compared to wake (Wagner et al., 2004), perhaps benefitting specifically from REM (Cai et al., 2009). These effects can be summarized as a de-contextualization of originally episodic experiences. During REM however the memory aspects that require future use and/or retrievability are selected according to some mechanism (Stickgold and Walker, 2013), re-bound with other fragments leading to novel permutations and creative insight, and are further consolidated. It is during these stages, and/or later in the night of sleep, that particularly emotional, important and future-relevant aspects of information appear preferentially in dreams (Malinowski and Horton, 2014b). We might assume, therefore, that emotional salience acts as a marker for activating memory fragments during REM sleep, that were decontextualized during the preceding non-REM stages of sleep, which together result in heightened retrievability of relevant memory fragments, ready for future autobiographical use (Malinowski and Horton, submitted).

Schwartz (2003) offers an explanation for the fragmentary appearance of EMs (as AMs) in dreams: as recent EMs are hippocampus-dependent (Marshall and Born, 2007), the information flowing from hippocampus to cortex during slow-wave sleep reflects the activation of more episodic information (engaging the hippocampus). However, during REM the information flow is blocked, with cortical-hippocampal flow increasing instead. Thus older, more semanticized memories (being more neocortex-based) feature more prominently. This is somewhat unclear as to why memory fragments appear more during REM, as opposed to there being merely fewer episodic references, however the switch in flow between hippocampus and neocortex could in part give rise to the interrupted and bizarre activation of memory fragments. Similarly, the increase in levels of cortisol across the night, peaking in the early hours of the morning, may also underlie the increasing levels of bizarre across the night (Payne, 2010).

As AM is multi-faceted, comprising both semantic and episodic elements (Renoult et al., 2012), it likely relies on consolidation from a full night of sleep and perhaps even and several iterations of sleep cycles over many nights. Furthermore Paller and Voss (2006) emphasize the cross-cortical storage across both sleep and wake, of declarative memory systems. This serves as a reminder of the complexity of both the memory and sleep systems involved in the encoding, consolidation, retrieval and re-consolidation of the majority of autobiographical information that we encounter in our daily, and nightly, lives.

Is Dreaming a Reflection of the Processes of Sleep-Dependent Autobiographical Memory Consolidation?

The field of dream science has begun to address the experiential aspects of sleep-dependent memory consolidation (e.g., Blagrove et al., 2011c; Desseilles et al., 2011; Horton and Malinowski, 2011; Payne and Nadel, 2004; Horton, unpublished). This may in part be due to the relatively challenging nature of manipulating AMs in the laboratory, compared with, for instance, episodic memories for word lists or images. It may also be due to the complexity of the AM system, comprising both episodic and semantic elements over time. Nevertheless the AM system does account in theory for the constructive and changeable nature of recollection of personal experiences over time, and largely falls in line with systems of consolidation and re-consolidation, as described above.

There exists only a small body of empirical work on which to base the theory that dreaming reflects AM consolidation during sleep. We have already briefly summarized the trends depicting the incorporation of AMs into dreams (see Constructive

Memory). However, many of these studies have investigated the memory sources of systematically-sampled dreams from a sleep-lab, at specific points in time. A fuller picture of the time-course of sleep-dependent consolidation can be sought by exploring the time between experiencing something in waking life and subsequently dreaming of it.

There are two broad trends: the day residue effect, which reflects the tendency to dream about experiences that occurred during the previous day and occurs in 65–70% of dreams (Nielsen and Powell, 1992), and the dream-lag effect (Nielsen, 2004; Nielsen et al., 2004; Blagrove et al., 2011a,b; van Rijn et al., 2015), which accounts for the tendency to dream about experiences that took place around a week (5–7 days) prior to the dream. The factors by which the dream-lag effect is produced are beginning to be identified, with REM-sleep providing the most reliable environment (Blagrove et al., 2011a) and memory salience increasing the likelihood of circaseptan (i.e., approximately week-long) incorporation (van Rijn et al., 2015). Explanations of dreaming, and in particular dreaming of specifically-aged experiences, are thus far largely only hypothetical (see discussions of Wamsley et al., 2010a; Murkar et al., 2014; Wamsley, 2014; van Rijn et al., 2015) and none yet have managed to account for the specific time-course of sleep-dependent memory consolidation processes. In part this reflects the variability in the time-course of setting down a memory into a specific, stable and long-term memory structure, as well as the complex nature of measuring this.

Nevertheless Marr (1970) proposed that consolidation rhythms guide the hippocampal-dependent store of the day's events, which maps on to day residues appearing in dreams. Similarly, the circaseptan rhythms of consolidation (see Frankland and Bontempi, 2005) might reflect the comparably circaseptan dream-lag effects. However, the resurgence in dream-lag explorations are bringing about a fuller picture of the factors affecting incorporation of AMs into dreams, even if there is as yet no empirical evidence either that memory consolidation takes a week for salient experiences, or that these processes reflect the dream-lag effect directly or indirectly.

An alternative method of exploring the relationship between dreaming and sleep-dependent memory consolidation is that dreaming trends could map on to specific effects of memory enhancement following sleep. For instance, the increased likelihood of dreaming of experiences relevant to waking life during slow-wave sleep as opposed to REM (Baylor and Cavallero, 2001) aligns with the tendency for episodic memory gains to be associated with slow wave sleep rather than REM (Rauchs et al., 2004; Smith, 2004). Similarly, Dumel et al. (2015) have recently found that infrequent dream recall is associated with low performance but high overnight improvement on a procedural (mirror-tracing) task. This mode of investigation attempts to link dreaming behaviors with consolidation trends. One challenge of this method is to demonstrate the distinction between being able to recall or report a dream, and actually dreaming. That is, any measure of dreaming needs to be validated somehow. Additionally, could one dream because they learn better, or learn better because they dream?

Two additional studies (de Koninck et al., 1990; Miller and Horton, unpublished) have attempted to link directly the content of consolidated information in sleep with dream content. de Koninck et al. (1990) attempted to correlate the proficiency of learning a new language with dreaming of that new language, finding that individuals (in a sample of four) who improved their language learning incorporated the new language into their dreams earlier and more extensively than those who made little progress. This design has been extended by de Koninck's team in a range of studies and makes use of language incorporations as a clearly operationalized and measurable mode of memory/learning incorporation into dream mentation.

The study by Horton involved exploring links between daily autobiographical experiences and dream content, finding that AMs that were incorporated into dreams were better recalled 3 weeks later than AMs that had not been incorporated into dreams. One criticism of this methodology is the difficulty in deciphering whether dreaming reflects memory consolidation, or whether memory improvements can be documented as a result of recording dream experiences which comprise a consolidated AM, thus activating and rehearsing those AMs in the process. However, indices of rehearsal were recorded and controlled for, and effects of memory improvement in line with dream trends remained. Nevertheless, methodological challenges still exist in this field (see A Model of AM Consolidation).

Overall empirical work attempting to link dreaming with memory consolidation is gaining momentum. Concurrently theoretical accounts of the relationships between memory fragmentation, hyperassociativity and memory consolidation are gaining prominence. Llewellyn (2013; Llewellyn and Hobson, 2015) has proposed one such theory, in which a function of dreaming of fragmented memory sources is to activate association networks, which lead to "elaborative encoding" and subsequent specific enhancement of episodic memory. Llewellyn's theory recognizes that dreams contain fragmented AMs and that those fragments are synthesized into a new image comprising hyperassociated fragments, with links being activated during sleep between elements that would not typically be linked during wake. Llewellyn proposes several novel ideas, such as the mechanisms by which hyperassociations are "junctioned" within the hippocampus, and that the increased activation of association networks leads to elaborative encoding. Similarly, Wamsley (2014) has been pioneering in her championing the case for considering dream content in sleep-dependent memory research.

We step away from the emphasis on episodic memory, noting that the formation of unitary dream images comprising memory fragments from perhaps several different experiences from waking, are not vastly different from the construction of AMs in waking life in the self-memory system (Conway, 2009). Thus we instead see the AM system as a guide for the construction of memory fragments into unitary images across both sleep and wake (indeed all stages of sleep, albeit operating under slightly different conditions over the sleep–wake cycle).

A Model of AM Consolidation

We have thus far reviewed the evidence for the involvement of AM across sleep and wake, noting that models of AM emphasize the re-construction of fragmentary pieces of information and

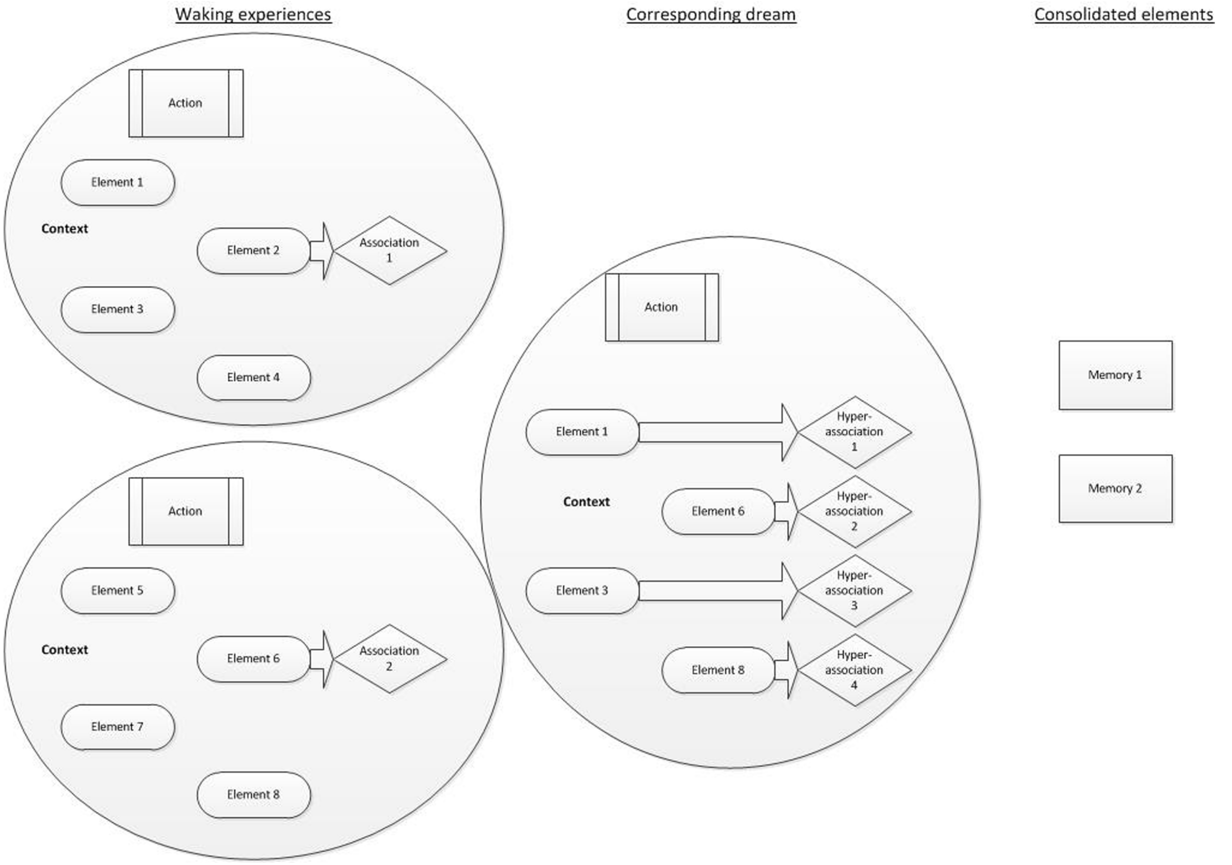

FIGURE 1 | AM consolidation model. Waking experiences are schematically represented as a circle, each containing numerous constituent fragments. Individual *elements* (such as characters, colors, objects present, sounds, etc.) feature alongside an *action* (such as shouting at a colleague) and a *context* (such as the environmental setting and an emotional tone). Focused waking cognition involves the selective activation of semantic *associations* to some of the fragments. The **corresponding dream** involves the synthesis of different fragments (elements, actions and a context, plus their possible associations) taken from previous waking experiences. Each of those fragments could elicit a *hyperassociation*. The **consolidated elements** are those that have been repeatedly or strongly activated. They remain preferentially accessible following sleep.

experiences at recall. The continuity of the AM system across sleep and wake, largely measured by dream studies, highlights that AM should be acknowledged in models of sleep-dependent memory consolidation. Here we emphasize not only that AM can elucidate memory consolidation processes, but also that AMs can benefit from sleep-dependent consolidation.

We therefore propose a model of AM consolidation during sleep, which is depicted schematically in **Figure 1**.

As events are experienced, they contain several multi-modal elements, which can each be measured and broken down. Such elements may reflect units or features, such as characters involved, details of the setting, sounds or conversations, actions, colors, emotions, thoughts or other sensory experiences. A feature of waking cognition is focussed thought (e.g., Hartmann, 2010a,b). As such whilst semantic associations are activated during waking, executive functions largely ensure that resources are allocated to goal-directed tasks. Experiences, information and perceptions from waking are broken down into unitary elements and activated offline during subsequent sleep. Each element activates associates, which may be somewhat distantly-related to the original element via hyperassociativity. Dreams reflect the activation of these elements and their associates. Furthermore dreaming cognition, in contrast to focussed-waking thought, lacks goal-directed control. Coupled with hyperassociation, semantic associations may be activated and take over consciousness, leading to a loose, changeable and unfocussed stream of activated memories, thoughts and perceptions, in part as a result of the attenuation of executive functions during sleep (e.g., Maquet, 2000). The activation of disparate memory elements, hyperassociates, and their re-combination into novel permutations gives rise to the relatively bizarre and improbable events within single dream images. Repeated activation of elements during sleep, typically depicting recently-learned information or experiences, is widely considered to result in the consolidation of the activated elements (Born and Wilhelm, 2012).

The novelty of this model is that (i) dreaming directly reflects the processes of sleep-dependent memory consolidation, (ii) memories or information can be consolidated if merely related to an experience (via hyperassociativity), rather than being directly experienced, (iii) AM provides an account of the engagement of the whole declarative memory system, as opposed to necessitating episodic and semantic memories to be consolidated via different

TABLE 1 | Application of the autobiographical memory consolidation model: child's dream.

Waking experience	Associated dream	Consolidated features
(i) Watching *Monsters Inc*. film in which monsters scare children in their bedrooms. Watching from my sofa in my living room, with baby sister and mother. This activates associated thoughts of scary creatures, such as a dragon from a favorite story book. (ii) Sat on Grandma's knee in her chair, playing a new game on Grandma's tablet. The object of the game is to fit puzzle shapes into a template. It makes a noise when the correct pieces are placed. This activates associated thoughts of photographs on the tablet, Grandma's cats (sat nearby) and feelings of mastery when I accomplish the puzzle.	A monster (like the main character in the film) scares me in my bed. I am very frightened. I want to leave but I have to complete a puzzle to escape. I have to try several times but I can't fit the last piece. I wake up just as the monster reaches me. This activates several hyperassociated elements such as being afraid of other specific film characters (who are usually friendly), being lost inside the tablet and seeing various shapes (within the puzzle).	Ability to fit the puzzle pieces together. Monsters can be scary.

The dream report has been taken from a 2.5-year-old child. The waking experiences have been provided by the child's mother and the hyperassociated elements are hypothesized.

TABLE 2 | Application of the autobiographical memory consolidation model: adult's dream.

Waking experience	Associated dream	Consolidated features
(i) Sat at the computer at my desk in my office, preparing for an upcoming presentation on memory to a non-specialist audience. Trying to think of examples of procedural memory that people can relate to. People talking in the corridor nearby. This activates associated thoughts of colleagues in the field, the organizer of the presentation event, and other work projects that require urgent attention. (ii) Listening to the radio whilst washing up in the kitchen. A song by a well-known artist is being played, about a woman who escapes the daily hassles of her family and work by getting on a train. This activates associated thoughts of the singer's husband (also well-known), own family commitments (needing to stock up on food to prepare better meals for the children) and work projects looming, such as the presentation described above.	Delivering a presentation (from (i)) on memory in a generic sports hall (an exam location) to people sat in rows behind small examination desks. The invigilator is the singer's husband (from (ii)). I try to pronounce a brain region but falter several times. The scene shifts to a busy, unfamiliar road. I'm walking along it, discussing my shopping list with the singer's husband again. We walk past his wife and wave. Several hyperassociated elements are activated, such as examination fears of nervousness, lack of preparation, brain regions I've been reading recently and images of the (unfamiliar) authors of related papers, hustle and bustle from the busy road, a memory of a newsagents from childhood, thoughts about my baby daughter's ability to wave when she recognizes someone. . .	Representation of the film character consolidates recognition of their face and voice. A need to shop for food for the children. Examples of procedural memory needed for the presentation. A need to prepare the presentation so to avoid being nervous, and faltering. (The emotional context has been removed.)

The waking experiences and the dream report have been taken from the first author's own experiences.

processes, and (iv) the fragmentation of AMs during sleep serves the function of decontextualizing them, rendering salient elements more easily integrated into existing networks, thus consolidating them efficiently.

Waking experiences are presented along with few associated thoughts and information, indicating a small degree of associated activation within focused, waking cognition. The consequential dream experience incorporates elements of the waking experiences, along with some new information and thus comprises novel permutations of the original AMs. Each dream element leads to activation of hyperassociated information. The subsequently consolidated features are those that have been repeatedly activated. These features may have been experienced in waking, in the dream or as associations of any element of these. There is therefore overlap between the original experiences, dreams, and consolidated features, in line with the constructive AM system. **Figure 1** presents a schematic of these processes.

We can provide illustrations of how this may work using related waking and dreaming thoughts, as depicted in **Table 1**. The child's dream exemplifies the typical emotionality of recalled dreams and how procedural and episodic elements can be combined within dream content, leading to independently consolidated features.

Table 2 presents an adult dream, depicting more mundane experiences and thoughts from daily life, reflective of more systematically-sampled dream content. The dream relates to the two waking life experiences and merges features of them, whilst individual elements of the waking life experiences have been broken down. The consolidated features arise from the repeatedly activated elements of the waking life experiences, the dream and the hyperassociations of the dream elements.

Predictions of the Model

The AM consolidation model emphasizes the continuity between AM and dreaming cognition, as such there should be more similarities than differences between the activation of memories and thoughts dreaming and waking. In addition a major testable claim of our model is that the more something appears in a dream, the better consolidated and integrated into existing networks that should be.

As dreaming depends crucially on AM, those with AM impairment should also see a reduction in dreaming and impairments in consolidation. We believe that these propositions fit with standard models of both retrograde (with respect to the former) and anterograde (with respect to the latter) amnesia. Furthermore retrograde amnesics should be able to dream, but would likely only dream of recent experiences, if their accessibility of more remote memories is impaired across sleep as well as wake. Anterograde amnesics should likely only dream of older experiences, though there may well be methodological challenges with sampling dream reports from such patients.

We acknowledge the methodological challenges associated with testing some of these claims but recognize that paradigms are developing that aim to demonstrate links between dream content, whether direct or metaphorical representations are incorporated, and subsequent consolidation (Horton, unpublished data; Wamsley et al., 2010b).

Methodological Note Concerning Sleep vs Dreaming

We wish to emphasize that we are not proposing that dreaming, *per se*, is a necessary and sufficient part of the memory consolidation process. Rather dreaming may reflect the processes of offline memory activation that leads to consolidation. Any mental content during sleep can give rise to the experience of having dreamt, providing waking occurs soon after and interference does not occur (Parke and Horton, 2009).Whilst these hypotheses are compelling, the data presented are largely preliminary and the field is still expanding. In particular the links between the sleep mentation and the nature of what exactly is being consolidated needs to be further refined. Nevertheless these data imply that there is something predictable about the nature of the sleep–wake cycle in relation to memory consolidation function. Animal studies are clearer here, although a review of these go beyond the scope of the present paper (however for a useful summary see Ribeiro and Nicolelis, 2004). Data from experimental studies also suggest that there is more continuity than discontinuity between memory functioning and consciousness across sleep and wake (e.g., Schredl and Hofmann, 2003). Similarly, some preliminary data has hinted that the content of daydreams can be directly linked to the subsequent improvement in a procedural dart-throwing task (Miller and Horton, unpublished data). These data provide evidence of the continuity of mental content as a reflection of procedural learning. The challenge is to integrate a theoretical explanation for this with the wealth of evidence underpinning current conceptions of sleep-dependent memory consolidation processes, which typically see sleep as providing an environment that differs substantially from waking functionality. It is essential to operationalize dreaming more specifically in order to enable predictions to be made about the continuity of cognitive processing across sleep and wake (Schredl and Hofmann, 2003).

We should also reiterate that we assume that the incorporation of AMs into dreams reflects the activation of AMs within the sleeping brain in a generally direct manner. That is, if something appears in a dream we deem it to be representative of some associated waking life experience. Whilst these manifestations may appear metaphorically or in a loosely associated manner, we should acknowledge that there exists some alternative theories of dreaming, which postulate that the representation of waking experiences into dreams are a compensation for the lack of conscious consideration during wake (e.g., Jung, 1934, 1948a,b). Freud also argued for dream content being far less reflective of waking life in his theory of repression.

Individual Differences, Implications for Creativity, and Clinical Considerations

The hyperassociative cognition typical of REM sleep can promote creativity and insight (e.g., Ritter et al., 2012). Yet disturbed sleep can lead to greater dissociation, also resulting in greater creativity (van Heugten-van der Kloet et al., 2015). How can these seemingly opposing views be aligned?

Disturbed sleep is recognized as a correlate of most diagnosable mental illnesses, both psychotic and neurotic/emotional in nature. As some individuals show a tendency toward creativity in waking it would follow, in line with the continuity hypothesis and its emphasis on holistic functioning over the full cycle of sleep and wake, that some individuals may be particularly affected by sleep's hyperassociative cognition. Some researchers have investigated these ideas with regards to creativity and psychosis (e.g., Llewellyn, 2011). In non-clinical contexts, "healthy" sleep can promote creativity in relation to problem solving, as novel insight results from hyperassociative cognition during sleep (Stickgold et al., 1999). When sleep is more disturbed dissociation can result, which in turn can lead to creative thinking. This creates a U-shaped relationship between sleep quantity and creativity. The question therefore remains as to how this may affect memory consolidation.

One could argue that the greater the fragmentation of autobiographical experiences during sleep, resulting in part from hyperassociative cognition, the greater the experience of dream bizarreness and subsequent creativity in waking. Such processing would also lead to greater de-contextualization of a remembered memory source, subsequently increasing its retrievability across different situations. According to our view this reflects an efficient mode of AM consolidation, resulting from obtaining non-disturbed sleep.

We propose that disturbed sleep would lead to impaired AM functioning. As AM comprises both memories about one's own life as well as a cognitive self, we hypothesize that disturbed sleep would impact on both the retrievability of AMs as well as the stability of the self.

Conclusion

We have presented a model of AM functioning across sleep and wake, such that memory sources of autobiographical experiences are fragmentarily activated during sleep and re-bound with other memory sources, as manifested via bizarre combinations of experiences in dreams. The rebinding of memory sources occurs when the brain enters a hyperassociative, reflexive state during both REM and non-REM sleep. Such processes are proposed to be reflective of sleep-dependent memory consolidation. There are therefore benefits of such hyperassociative and creative cognitive processing, as under the right conditions, they can lead to de-contextualization of experiences and subsequent increased accessibility of a memory.

This is the first time that AM, engaging both the semantic and episodic (declarative) memory systems, has been proposed to account for the activation of hippocampal–cortical regions during sleep. We argue that studying the composition of dreams provides a useful methodological tool for further exploring the cognitive processes of sleep-dependent memory consolidation.

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Metaphor and hyperassociativity: the imagination mechanisms behind emotion assimilation in sleep and dreaming

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In this paper we propose an emotion assimilation function of sleep and dreaming. We offer explanations both for the mechanisms by which waking-life memories are initially selected for processing during sleep, and for the mechanisms by which those memories are subsequently transformed during sleep. We propose that emotions act as a marker for information to be selectively processed during sleep, including consolidation into long term memory structures and integration into pre-existing memory networks; that dreaming reflects these emotion assimilation processes; and that the associations between memory fragments activated during sleep give rise to measureable elements of dream metaphor and hyperassociativity. The latter are a direct reflection, and the phenomenological experience, of emotional memory assimilation processes occurring during sleep. While many theories previously have posited a role for emotion processing and/or emotional memory consolidation during sleep and dreaming, sleep theories often do not take enough account of important dream science data, yet dream research, when conducted systematically and under ideal conditions, can greatly enhance theorizing around the functions of sleep. Similarly, dream theories often fail to consider the implications of sleep-dependent memory research, which can augment our understanding of dream functioning. Here, we offer a synthesized view, taking detailed account of both sleep and dream data and theories. We draw on extensive literature from sleep and dream experiments and theories, including often-overlooked data from dream science which we believe reflects sleep phenomenology, to bring together important ideas and findings from both domains.

Keywords: sleep, dreaming, emotion, memory, hyperassociativity, metaphor

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Aims of the Paper

The ways in which our emotions function (or malfunction) in waking life are greatly affected by sleep. For example, sleep benefits the consolidation of emotional memories, and enables us to regulate our emotional reactions (see Emotion-Processing Theories of Sleep). Many theories, of both sleep functioning and of dream functioning, exist to account for the large body of data demonstrating the importance of sleep and dreaming for waking-life emotions. However, often these theories suffer from a lack of integration: theories of sleep do not adequately consider dream research data, and theories of dreaming do not adequately consider sleep research data. Though recently there has been some evidence of a move toward a more integrative approach (e.g., Payne, 2010; Perogamvros et al., 2013; Wamsley, 2013, 2014) sleep and dream theories tend to remain relatively disparate. One of the potential barriers is the skepticism with which dream reports are sometimes viewed; but recently researchers have argued that (a) dream reports are transparent accounts of dream experiencing (Windt, 2013), and (b) dreams are direct reflections of sleep processes (e.g., Payne, 2010; Wamsley, 2013, 2014). As such we argue that greater attention should be paid to dream research and theorizing, as dreams can provide phenomenological accounts of sleep processes.

On the basis of neuroscientific and behavioral data we propose an emotion assimilation function sleep and dreaming, whereby emotions act as a marker for the salience of a memory, thus prioritizing its subsequent consolidation. Emotional memories are then strengthened and assimilated into existing memory schemas during sleep, resulting in memory transformations such as creativity, insight, and gist extraction. An outcome of this process may also be the amelioration of the emotional intensity of the memory. We argue that dreams can be seen to reflect these sleep-dependent mental processes. Our proposed theory attempts to decipher explicitly both one of the mechanisms by which a to-be-remembered item may be selected for subsequent consolidation during sleep (emotional intensity), and further some of the possible mechanisms by which the items may be subsequently assimilated into the wider memory schema, as reflected by dream content (metaphor and hyperassociativity/bizarreness). We review an extensive body of literature and evidence from the sleep and dreaming fields to explore the effects of sleep on emotional functioning. By critiquing current theories we consider what any new approach needs to achieve in order to fit the data across neuroscientific, behavioral, lab-based and home dream recall domains (Desseilles et al., 2011). Our theory is proposed as *a* function of sleep and dreaming, rather than the function of sleep and dreaming: we recognize that there are likely to be many functions of sleep and dreaming, and that the theory likely will not account for all types of dreaming.

In the following sections we: (1) review some emotion-processing theories of sleep; (2) review some emotion-processing theories of dreaming; (3) consider some arguments for and against currently existing emotion-processing theories of dreaming, noting in particular what the existing theories lack; (4) outline our proposal for an emotion assimilation function of sleep and dreaming; and (5) consider two of the mechanisms that we believe underlie emotion assimilation: metaphor generation and hyperassociative thinking. Finally, we suggest some ideas for future directions and draw conclusions about our emotion assimilation theory. Throughout we focus on data from human rather than animal studies and consequently draw conclusions relevant to human functioning.

Emotion-Processing Theories of Sleep

Sleep and Emotional Reactivity

Evidence abounds for the importance of sleep for emotional functioning in waking life. For instance, studies have found that sleep benefits emotional reactivity in waking life: sleep deprivation increases reactivity to negative stimuli (Franzen et al., 2009), to anger and fear emotions (Gujar et al., 2010), and indeed also to positive stimuli (Gujar et al., 2011). The latter indicates an overall overreactivity to emotional stimuli following sleep deprivation, suggesting a general modulating effect of sleep on emotions. A review of insomnia and emotions found that insomnia is associated with various mood disorders (e.g., depression and anxiety) and heightened emotional reactivity (Baglioni et al., 2010). Additionally there is compelling evidence that the hormones cortisol and epinephrine contribute to the selective processing of emotional material during sleep (Cahill and Alkire, 2003; Payne and Nadel, 2004), with levels being particularly heightened during REM.

Evidence such as this has led to several theories suggesting that a function of sleep includes emotion regulation or processing. Walker's (2009) review concluded that REM sleep facilitates the recall of emotional memories, whilst simultaneously reducing the emotional impact. One particularly pertinent study found that the hippocampus (for memory) and the amygdala (for emotion) are both more active when participants are shown emotional compared to neutral stimuli, but when shown the same material months later only the hippocampus is more active (Dolcos et al., 2005), suggesting the memory is strengthened for recall, but emotional reactivity is weakened. Walker hypothesized that this process occurs during sleep, and thus sleep loss results in long-term affective issues, such as chronic anxiety. Walker and van der Helm's (2009) 'Sleep to remember, sleep to forget' hypothesis adds to this theory that if this amelioration of emotions is not achieved on the first night, the process will continue on subsequent nights. Thus, the process occurs in three stages: memory consolidation, memory integration, and emotion amelioration. Further, sleep may prepare the individual for next-day emotional functioning, as proposed by Goldstein and Walker (2014), whose model focused on circadian (i.e., circa 24-h) rhythms.

However, there are also some conflicting results in studies investigating the effect of sleep on mood. One study found that sleep deprivation alleviates depressive symptoms (Vogel et al., 1975), and the same was found also in a study with a non-depressed sample, for whom deprivation was related to emotional adaptation to a negative stimulus (Lara-Carrasco et al., 2009); these findings suggest that it is the *lack* of sleep, rather than the presence of it, that enhances emotion regulation. Vandekerckhove and Cluydts (2010) theory, which draws similar conclusions to those cited above, includes also a suggestion that can account for such disparate findings. The authors suggest that emotional disorders such as depression may be due to an overstimulation of sleep processes (such as greater amygdala activation, higher amounts of REM sleep, and more negative affect in dreams), which results in an excessive emotional response, particularly to negative stimuli. This would explain why sleep deprivation benefits depressed individuals. Although this does not directly explain why sleep deprivation also benefits non-depressed individuals, it may be speculated that during the first night following exposure to a negative stimulus, sleep overstimulation (in response to the stimulus) may result in lack of adaptation, and thus deprivation aids adaptation; but perhaps on following nights the trend would be reversed as sleep adjusts to the stimulus, and then sleep may aid further adaptation. This is in line with Walker's (2009) idea that the process occurs over multiple nights until adaptation is achieved. A similar model has been espoused in relation to dream incorporation of negative stimuli, the Disruption-Avoidance-Adaptation model (Wright and Koulack, 1987), which will be explored further later, in Section "Wright and Koulack: The Disruption-Avoidence-Adaption Model."

Sleep and Emotional Memory Consolidation

Studies have also found that sleep is beneficial for emotional memory consolidation. For instance, recall of emotional stimuli has been shown to be better after sleep than wakefulness (Hu et al., 2006); this is especially true for late-night, rapid-eye-movement- (REM-) rich sleep (Wagner et al., 2004), although recent evidence has demonstrated the complementary roles of both slow-wave sleep and REM (Cairney et al., 2014). Similarly, emotionally related items are recalled more than neutral items following sleep using a false memory task (Horton and Knott, unpublished manuscript). Sleep also 'unbinds' waking-life stimuli, selectively consolidating emotional rather than neutral aspects of it, both over the course of a night and during a nap (Payne et al., 2008, 2015).

On the basis of such lines of evidence as these, several researchers have argued that sleep is integral to emotional memory consolidation (e.g., Stickgold et al., 2001; Payne, 2010; Wamsley and Stickgold, 2011). This theory of sleep, thought to be reflected in dreams (Wamsley, 2014), is somewhat divergent from the emotion-processing theories of sleep and dreams, in that instead of waking-life emotional experiences being dreamt of in order to regulate or process emotions, these memory-centered theories focus on the integration of memories. According to these theories the meaning of an experience is extracted, the overall 'gist' of the memory rather than specific details are consolidated for recall and use, the emotionally salient rather than the neutral aspects of a memory are strengthened for recall but the emotion itself is dampened, and the memory is 'unbound' to enable memories to be reorganized in novel and creative ways, which facilitates creative thinking during wakefulness. Thus, it is a theory of the *assimilation* and reordering of emotional experiences, rather than the regulation or processing *per se*; but assimilation includes the dampening of emotions as a natural corollary of the process, and indeed perhaps is one (of many) of the functions of the process.

Stickgold and Walker (2013), in their 'triage' theory argue that it is now "incontrovertible" (p. 139) that a sleep-dependent memory consolidation process exists; but what remains to be discovered is how we decide which memories are selected for consolidation during sleep. They postulate that stimuli are reviewed at the point of encoding, and 'tagged' if deemed sufficiently salient and relevant for future use. Three ways in which such information may be tagged are suggested: the emotional intensity of the experience, the future relevance of the experience (e.g., knowing that the information will be useful for a reward or a test later), and the deliberate intention to retain the information. Once the item has been selected for consolidation, two main processes then occur: item integration, in which newly learnt memories are assimilated into pre-existing memory schemas, and multi-item generalization, in which new items are combined into a new schema. We re-visit these ideas in relation to emotional processing in Section "Emotion-Processing Theories of Dreaming" shortly in light of evidence from dream science.

Mapping Sleep onto Dreams

Sleep is the primary concern of the evidence and theories discussed so far. However, some researchers do reference dream research, with some even mapping emotion-processing theories of sleep onto theories of dreaming (e.g., Walker, 2009; Walker and van der Helm, 2009; Desseilles et al., 2011). However, such speculations often rest on an idea of REM sleep specifically being related to dreaming, since it is usually REM sleep that is implicated; or at least, REM sleep being related to a type of dreaming that is highly emotional, as well as vivid, imagistic, bizarre, complex, and so on (e.g., van der Helm and Walker, 2012). But as many researchers have shown (e.g., Solms, 2000; Domhoff, 2003), REM sleep and dreaming are doubly dissociable, and NREM dreams can take on the typical properties of REM dreams, especially later in the night (Wamsley et al., 2007; Nir and Tononi, 2010; Payne, 2010). Thus, emotion-processing theories of dreaming must look at dream research specifically, rather than extrapolating from REM sleep to dreams (see also Desseilles et al., 2011, for a review of the relationships between brain processes, sleep and dreaming). In the next section we outline some emotion-processing theories that are primarily based on dream research.

Emotion-Processing Theories of Dreaming

Hartmann: Dreams "Calm the Storm"

One of the best known theories of emotion-processing in dreaming is that of Hartmann (1996a, 1998, 1999a,b, 2011), who drew conclusions about emotion-processing during dreaming from his work with victims of trauma. He argued that dreams picture waking-life emotions, and that this can be perceived particularly well in nightmares: for example, feelings of terror, vulnerability, or guilt might be pictured in what he termed 'explanatory metaphors' in dreams, such as being engulfed by a tidal wave. He suggested that this picturing of waking-life emotions in dreams enables the emotional memory to be connected to other related memories already stored in the dreamer's mind, in order to reduce the emotional intensity and distress caused by the experience by comparing it to other experiences ("calm the storm"); and second, to prepare the dreamer for any future experiences that might occur. His theory recalls an earlier stress-mastery theory of dreams (Breger, 1967), in which it was suggested that we dream of our stressful waking-life experiences in such a way that the experience is "symbolically blended" (p. 24) with past memories, which enables the eventual mastery of the experience; and both of these earlier dream theories are strikingly similar to Walker and van der Helm's (2009), discussed in Section "Sleep and Emotional Reactivity." In all three accounts, at least one of the functions of sleep/dreaming is proposed to be the reduction of the emotional intensity of waking-life experiences.

Levin and Nielsen: The AMPHAC/AND Model

A similar proposal has been made by Levin and Nielsen (2007, 2009), Nielsen and Lara-Carrasco (2007), Levin et al. (2010), but with the emphasis on the reduction of fear emotions specifically, in their AMPHAC/AND model. According to the model, the dreaming process works in three stages: memory-element activation, in which memory elements (as opposed to intact memories) are activated; memory-element recombination, in which memory-elements are re-organized into a narrative; and emotional expression, which is often fear. As in Hartmann's and Breger's theories in the previous section, there is the suggestion that the new (emotional) memories are compared with other memories in order to recombine them into something new. In the AMPHAC/AND model, this is the reason for dream bizarreness: the recombination of memory-elements makes dreams bizarre, because it incorporates disparate elements of memory and blends them together. The authors further suggest that when the process dysfunctions, disturbed dreaming (nightmares and bad dreams) occur, and it can also fail when the memory-elements are not recombined in novel ways but in ways that have already been experienced, which leads to recurrent dreaming. They further note that current situation and individual differences affect how well this process can function; nightmares are more likely when the individual experiences greater 'affect load' (amount of stressful/emotional experiences) and 'affect distress' (the predisposition toward such experiences being problematic), which vary as a product of situation and personality. These important ideas will be explored later.

Revonsuo: The Threat Simulation Theory of Dreaming

Another theory that proposes, like Hartmann, that dreaming prepares the dreamer for future experiences is Revonsuo (2000), Valli et al. (2005) Threat Simulation Theory (TST) of dreaming. This is an evolutionary explanation of dreaming, supported by a large amount of data concerning nightmares, the prevalence of fear in dreams, and the repetitive nature of some dream acts. The TST proposes that dreaming provides an opportunity to rehearse possible outcomes that may be useful to survival during wakefulness. One of the central propositions of the TST is that dreams are not an accurate reflection of waking reality, but rather are biased toward threatening experiences. Whilst the disproportionately high presence of negative emotions have been demonstrated in a large sample of dreams (Hall and Van de Castle, 1966), systematically sampled and self-rated dream reports indicate that emotions in dreams are more varied and balanced (Schredl and Doll, 1998; Sikka et al., 2014); however, the TST may still apply to the subset of dreams that represent threat and fear emotions.

Cartwright: The Emotion Regulation Function of Dreaming

Cartwright (2011), on the basis of her extensive work with divorced individuals (e.g., Cartwright et al., 1984, 2001, 2006; Cartwright, 1991), also proposed an emotion-regulation function of dreaming. She proposed that if we experience negative waking-life experiences and dream of those experiences in specific ways, such as with negative emotions and with time variance (dreams set in the past, present, and future), then we are more likely to show improvement on coping with those experiences than if we do not dream of them or dream of them in the wrong way, such as with neutral emotions or without time variance (dreams set exclusively in the past). Similarly, studies with alcoholics have indicated that dreaming of alcoholism, particularly in negative tones, is related to recovery (Choi, 1973; Kibira, 1995; Parker and Alford, 2010). Although Lara-Carrasco et al.'s (2009) study (see Sleep and Emotional Reactivity) suggested a link between *lack* of emotional adaptation and the appearance of negative emotions in dreams, it may be that this difference occurred because of the different methodologies: Cartwright's studies measured naturalistic stimuli over long time periods, whereas Lara-Carrasco et al. (2009) used a stimulus-manipulation paradigm over a single night. It may be that the emotion-regulation function is only effective for naturalistic, salient, and/or long-lasting waking-life experiences such as divorce. This is in line with Walker's (2009) assertion that emotion amelioration may not be achieved on the first night but may require several nights of processing: it may be that incorporation *initially* has detrimental effects on adaptation, but, longer-term, incorporation is beneficial. This is what is proposed by the next model by Wright and Koulack (1987).

Wright and Koulack: The Disruption-Avoidance-Adaptation Model

Wright and Koulack's (1987) model was designed to account for apparently contradictory findings relating to dream incorporation of emotional waking-life experiences and adaptation to those experiences. In the Disruption-Avoidance-Adaptation model, it is suggested that incorporation (disruption), non-incorporation (avoidance), and finally adaptation are all points along a dream adaptation continuum. First, a stressor is experienced in waking life, and this disrupts sleep and so is incorporated into a dream. This is not necessarily adaptive, in line with the findings that incorporation on the first night after exposure to a negative stimulus is related to maladaptation (Lara-Carrasco et al., 2009), but is a point along a continuum that may *eventually* lead to adaptation. Secondly, the dream avoids that material or complements it in some way, for the purposes of re-finding emotional homeostasis. Disruption/incorporation and avoidance/non-incorporation may then oscillate for as long as necessary until the material is mastered. This last point puts the model on similar ground to theories noted earlier that suggest the process is long term and iterative. It may be that this model is related to the findings regarding the 'dream-lag effect,' which shows that waking-life experiences – particularly personally significant ones – are incorporated into dreams on the first night after having been experienced, and then again around 5–7 days later, and the second time they appear they are more abstract (Nielsen and Powell, 1992; Blagrove et al., 2011b; van Rijn et al., 2015). These periods of incorporation, non-incorporation, and re-incorporation with more abstraction may reflect the disruption-avoidance-adaptation process postulated by Wright and Koulack (1987) and – potentially – the processes of memory stabilization, elaboration and consolidation as proposed by Walker (2005). Wright and Koulack (1987) further note that this process only occurs for stressors that are potent enough not to be able to be dealt with by the waking brain alone; benign stressors may be mastered during wakefulness and so do not need incorporation into dreams for mastery to occur there.

Convergences between the Theories

There are some clear similarities between the theories, both of sleep and of dreaming: emotion-processing during sleep/dreaming is a long-term, iterative process involving both incorporation and non-incorporation of emotional material, and the process involves the stages of memory activation during sleep and dreaming, recombination of those memories (associatively with other memories and with imagination), and finally emotional adaptation. In the next section we consider a number of arguments in favor of and against the emotion-processing theories outlined here. The arguments in favor of the theories that come from sleep research have been noted in Section "Emotion-Processing Theories of Sleep" and will not be repeated here.

Arguments for and Against Emotion-Processing Theories

Arguments for Emotion-Processing Theories of Dreaming

We Preferentially Dream of Emotional Waking-Life Experiences

As a starting point, it is necessary for any emotion-processing theory of dreaming to show that we preferentially dream of our emotional waking-life experiences over neutral experiences, since if we dream of emotional and neutral waking-life experiences equally it would be more difficult to argue that dreams serve a specific emotion-processing function. Several studies have demonstrated the tendency for dreams to reflect emotional experiences from waking life (Schredl, 2006; Horton et al., 2011; Horton, 2012; Malinowski and Horton, 2014a), and a wealth of content analysis studies indicate that dreams generally reflect waking-life concerns (e.g., Domhoff, 2003). Whilst this could be accounted for by a recall bias, systematically sampled dream reports still show this trend (Schredl and Doll, 1998). Moreover, waking-life experiences that are incorporated into dreams are more emotional than those that are not incorporated (Schredl, 2006; Malinowski and Horton, 2014a). Thus, it can be said quite conclusively that waking-life emotions tend to be incorporated into dreams, and with more frequency than waking-life experiences that are less emotional.

Emotional Intensity is a Marker for Recall

Since we know that dreams preferentially incorporate emotional experiences, it then follows to query what purpose emotionality may serve. It is known that emotion is important for memory recall: for example, memories that are emotional are even easier to recall than memories that have been specifically attempted to be remembered (Heuer and Reisberg, 1990). Similarly, emotional memories (regardless of valence) are recalled better than neutral ones (although there are differential effects for negative and positive emotions: Kensinger, 2009). Walker (2009) notes that emotional memories are retained, though the emotion itself is reduced over time. The reason for this may be that it is useful to have an emotional reaction to a stimulus initially in order to gage which experiences should be recalled and which forgotten, but not to retain those emotional reactions alongside the memory. That is, emotions are a useful signifier for tagging memories to be remembered – for example, to avoid negative experiences and repeat positive ones – but it would be detrimental to keep experiencing the emotions each time the memory is activated. Thus, emotional reactions to experiences are an instant, automatic way of alerting ourselves to the importance of those experiences. This aligns with Stickgold and Walker's (2013) triage theory, in which they suggest that salient information is 'tagged' for consolidation by emotional arousal, future relevance, and/or deliberate intention.

Further evidence for this claim comes from the Fading Affect Bias (FAB; Walker and Skowronski, 2009; Ritchie et al., 2014), whereby the negative emotional tone of an autobiographical memory fades faster over time than the positive emotion. This has been evidenced to as quickly as 12 h following the original experience (Gibbons et al., 2011), possibly emerging following a period of sleep. The FAB has been proposed to reflect positive coping, overcoming past experiences, and recalling events in line with the current conceptions of the self. In addition, as we outline later, the heightened emotionality associated with a memory may signify its importance and need for consolidation, for ease of subsequent retrieval, with the emotionality being ameliorated once that purpose has been achieved. The FAB has been shown to occur in memories for dreams (Ritchie and Skowronski, 2008), although it remains to be seen whether dreaming, or sleep, actively contributes to the effect.

Dreaming of Emotional Waking-Life Experiences is Related to Subsequent Adaptation

Next, any emotion-processing theory of dreams needs to be able to demonstrate that dreaming of emotional waking-life experiences results in improved adaptation to them compared to non-incorporation. This has been demonstrated in Cartwright's laboratory as discussed in Section "Cartwright: The Emotion

Regulation Function of Dreaming." She has also studied levels of depression in non-depressed students pre-sleep and post-sleep, and linked this with dream content (Cartwright et al., 1998). Students with moderate scores on the Profile of Mood State (POMS) scale for depression had three time as many negative dreams at the start of the night than toward the end and exhibited a significant reduction in depression scores from night to morning, whereas students with low scores had equal numbers of positive and negative dreams and no alteration in scores from night to morning. This accords with her finding that among depressed divorcees, participants who had more negative dreams at the beginning and fewer at the end were more likely to have been in remission at follow-up 1 year later than those who had more negative dreams and the end and fewer at the beginning of the night. Thus, in addition to the studies discussed earlier, it has been shown that progressive dreaming across the night (negative to positive) is related to improved mood, both short-term and long-term, in both a depressed and a non-depressed sample.

Summary of the Evidence for Emotion-Processing Theories of Dreams

Thus these pieces of evidence show that: (1) dreams preferentially incorporate emotional experiences; (2) emotional experiences are more likely to be recalled than neutral ones; (3) sleep may facilitate the amelioration of emotional experiences; and (4) there is a relationship between incorporating emotional experiences in dreams and adapting to those experiences. Taken together, they provide evidence for emotion-processing theories of sleep and dreaming, illustrating that emotionality likely 'tags' a memory for recall, and thus such memories appear later in dreams, perhaps for the function of ameliorating and/or adapting to those experiences.

Arguments Against the Emotion-Processing Theories

The Evidence is Correlational, Not Experimental

It has been argued that since Cartwright's studies were correlation rather than experimental (the stimuli were not manipulated), causality cannot be inferred (Blagrove, 1992, 2011): it might be that, rather than specific dreams resulting in coping ability, coping ability may lead to specific dreams. For example, well-adapted divorcees might be capable of accepting the negativity of their situation and thus dream negatively, whereas divorcees who do not adapt well may be stuck in the past happiness of their marriage and thus have dreams that are set in the past. Thus, the dreams may more simply be a carry-over of waking-life coping mechanisms rather than a coping mechanism outside of wakeful cognition.

More generally, any relationship between emotional processing and dreaming of emotional material needs to be subject to systematic comparisons of dreaming versus not-dreaming. Some theories of dreaming, such as the TST, Hartmann's "calm the storm" and Cartwright's "emotion regulation function" theories, emphasize the role of dreaming, as opposed to sleep *per se*, in the processing of emotions. Whilst the other theories use dreams to evidence the processing of emotion during sleep, they typically do not assume that dreaming is anything more than a reflection of offline processing during sleep. At present the methods for sampling dreams both in and out of the laboratory are not yet sophisticated enough to make such a distinction between sleep with dreaming and sleep without dreaming, with dream recall being the only means by which researchers can find evidence of having dreamt (Kahan and Horton, 2012). As such, until effects of dreaming can be experimentally manipulated, we must draw tentative conclusions about any function of dreaming as distinct from a function of having slept. However, some studies have begun to develop methods for matching improvements in specific autobiographical memories with dreams of those precise experiences, noting that emotional experiences are more likely to feature in dreams than neutral ones and that those experiences are preferentially recalled more accurately 2 weeks later (Horton, 2012).

Dream Theories Focus on Different Levels of Inquiry to Sleep Theories

Following on from this view, any theory of emotion processing needs to be able to account for the behavioral (as well as the neuroscientific) profile of emotion processing in sleep (as summarized in Section "Emotion-Processing Theories of Sleep"), as well as in dreaming. At present the theories of emotional processing in dreams can, in part, explain the preferential processing of emotional memory (compared to emotionally neutral memories), but they cannot be mapped onto the trends concerning the preferential consolidation of emotional memory following sleep (aside from Horton, 2012, as noted above). Wamsley's work exploring the experience of dreaming alongside memory processing in sleep (Wamsley et al., 2010; Wamsley, 2014) has been exemplary in attempting to link these domains, though vast methodological improvements are required before conclusions can be confidently drawn concerning the specific role of dreaming in emotional processing during sleep.

Valence does not Influence Incorporation

The theories of emotion-processing in Section "Emotion-Processing Theories of Dreaming" focus specifically on negative emotions: Cartwright's (2011) theory came from work with individuals going through divorce, Hartmann's (1996a) theory was developed from work with trauma victims, Levin and Nielsen (2007, 2009) focus specifically on fear extinction, and Wright and Koulack (1987) on stressful experiences. Thus, these accounts of dream functioning would suggest that dreams particularly incorporate particularly negatively emotional, and/or stressful waking-life experiences. However, this is not the case. Whilst there is an array of literature concerning negative emotions in dreams, the evidence from dream science suggests that experiences typically incorporated into dreams are more emotionally *intense* than those that are not incorporated, but are not specifically negatively valenced (Schredl and Doll, 1998; Schredl, 2006; Horton et al., 2011; Malinowski and Horton, 2014a). Some studies indicate that there is a 'negativity bias' in dreams – the tendency for dreams to be more negatively than positively valenced (Hall and Van de Castle, 1966; Snyder, 1970; Nielsen et al., 1991; Domhoff, 1996) – but others have found a balance between positive and negative emotions in dreams (Strauch and Meier, 1996; Kahn and Hobson, 2002; St-Onge et al., 2005). Furthermore, studies that have compared external ratings of emotions to participants' self-ratings of emotions find that external raters overestimate negative emotions in dreams compared to what the dreamers themselves perceive in the dreams (Schredl and Doll, 1998; Sikka et al., 2014), indicating that it is the method that produces the negativity bias. In other studies, the top self-reported emotion has been some form of joy, elation, or excitement (Howe and Blick, 1983; Fosse et al., 2001).

In a similar vein, as reported in Section "Emotion-Processing Theories of Sleep," sleep deprivation affects not only negative waking-life emotional reactivity, but positive reactivity too (Gujar et al., 2011); the authors proposed that sleep loss not only has detrimental effects on the processing of negative stimuli, but has bi-directional effects on emotions. Thus, following this line of evidence, it may be that rather than just enabling adaptation to negative stimuli, sleep more generally facilitates lower levels of reactivity to emotional stimuli. Similarly Carr and Nielsen (2015) have recently found that participants scored higher on a primed associational breadth task following REM but not NREM sleep nor a period of wakefulness, and, moreover, the effect was stronger for positive over negative stimuli, again demonstrating that positively valenced experiences need to be taken into consideration when considering the function of sleep or dreaming on waking life emotions.

Taking the discussion back to dreams, it may be said then that incorporating emotional experiences into dreams is either a reflection of or is itself instrumental in this process, through the assimilation of emotional experiences into the memory system (though the latter view is particularly challenging to evidence). The detrimental effects of sleep loss and/or lack of dream incorporation of emotional stimuli may be more obvious, more pronounced, and/or of more clinical relevance for negative stimuli, but the evidence for positive emotions necessitates a consideration not only of adaptation to negative experiences, but also a more general discussion of assimilation and amelioration of all emotional experiences in sleep and dreams. This is what has been achieved in sleep research theories (see Emotion-Processing Theories of Sleep), whereby both positive and negative emotions are accounted for: dream research theories would thus also benefit from a consideration of such data and theories as these.

Emotions vs. Stress

Just as there is a lack of evidence for negatively emotional waking-life experiences being preferentially incorporated into dreams over positive ones, so there is a lack of evidence for stressful experiences over non-stressful ones, whereby stressfulness is conceived of as a specifically negative and aversive longer-term response state (Kasl, 1995), as opposed to emotion which can be negative or positive and which is typically shorter-lived. Furthermore an emotion may elicit an associated subjective feeling, and one such recognized feeling is that of stress. This lack of evidence argues further against some of the dream theories, which specifically discuss stressful waking-life experiences (Breger, 1967; Wright and Koulack, 1987). While there is some evidence that particularly unusual stressful experiences such as trauma are dreamt of (see Barrett, 1996; Punamäki, 2007, for reviews), studies that have measured the effect of more usual stressful experiences on dreams have not found the same pattern. Malinowski and Horton (2014a) measured the emotionality and stressfulness of waking-life experiences separately, and found that experiences that were incorporated into dreams were more emotional, but no more stressful, than those that were not incorporated. Similarly, Delorme et al. (2002) found no effect of examinations on the dreams of students, whether the dreams were measured for direct effect or indirect effect (such as levels of stress or threat emotions in dreams), even though wakeful stress was higher during the examination period than a control period, demonstrating again that stressful experiences do not necessary result in dream incorporation.

Wright and Koulack's (1987) model could argue that examinations are relatively benign and can be adapted to during wakefulness, and so can account for this discrepancy. Indeed, some of the other results in Delorme et al. (2002) support this theory. When looking at students' coping mechanisms for the examination period, students who used problem-solving in waking life did not have incorporations of the examinations, whereas using positive reappraisal in waking life – making the problem seem less distressing without solving it – correlated with problem-solving in dreams. The inference is that incorporation of a relatively non-stressful experience becomes necessary if it is not adequately dealt with in waking life. Thus, in this view, it is not merely the level of stress intensity that determines whether or not a stressor needs to be incorporated into dreaming in order to be processed, but also ability to cope with the stressor, highlighting a role for individual differences. This will be explored further in the following section.

Individual Differences

For some individuals, dreaming of negative waking-life experiences may actually have the opposite effect to mastering that material, in that it may result in an increase in distress, rather than a decrease. This is in line with Levin and Nielsen's (2007, 2009) assertion that 'affect distress' (the predisposition to be distressed by difficult experiences) mediates whether the dreaming process is to function or dysfunction (become a nightmare or bad dream). Though Levin and Nielsen do account for this factor, many theories do not. Research has shown that nightmare distress (the amount of distress an individual feels about having a nightmare) is more strongly related to well-being than nightmare frequency (Belicki, 1992; Blagrove et al., 2004). Thus, for some individuals, having highly emotional experiences leads to dreaming of the experience – and they may also be predisposed toward such dreams becoming nightmares – and those dreams/nightmares in turn result in more waking-life distress. We have found individual differences that support this contention: individuals who score highly on neuroticism, indicating trait emotional lability, also score highly on a scale that measures how often their waking-life emotions affect their dream emotions and vice versa (Malinowski and Horton, unpublished manuscript).

Waking-life stress has also been shown to relate to experiencing recurrent dreams: active recurrent-dreamers (but not past- or non-recurrent dreamers) had more recurrent dreams in a period leading up to examinations than after (Duke and Davidson, 2002). If recurrent dreams are a malfunction of the 'normal' assimilation process of dreaming whereby dream material stagnates and repeats rather than progressing and processing (as suggested by Levin and Nielsen, 2009), then this would indicate that for some individuals waking-life stress results in a malfunction of the dream process (i.e., an increase in recurrent dreams). Being an active-recurrent dreamer has also been shown to be related to a host of waking-life issues summarily described as low levels of 'psychological well-being,' a measure that includes levels of waking-life depression, stress, and anxiety (Brown and Donderi, 1986). This research strengthens the argument that individual differences must be taken into account in considering dream function.

Individual differences may also account for Cartwright's findings: individuals who were predisposed toward coping with their divorce are more likely to have certain types of dreams (such as with time variance), while those predisposed toward failing to cope are more likely to have other types (such as stuck in the past). Indeed, earlier research found that participants who were high in 'neuroticism' had more dreams set in the past than in the present (Cohen and Cox, 1975). So it may be that predispositions determine what kind of dream a person will have, rather than the dream determining a person's ability to adapt.

Situational Differences

In addition to individual differences, situational differences affect whether incorporation of highly emotional experiences occurs, or whether non-incorporation follows, and the extent to which this relates to adaptation. In Levin and Nielsen's (2007, 2009) model this is called affect load (amount of stressful or emotional experiences an individual is experiencing). For example, though some evidence such as Cartwright's indicated a potentially beneficial role for incorporation, Lavie and Kaminer (1996), who worked with victims of trauma, found that adaptation was not related to dream incorporation of the trauma but to repression of it (and an overall repressive coping style). Thus it may be that higher levels of stress require a repressive coping style, which includes dream repression, whereas lower levels of stress may be better served by focusing on the experiences and mastering them, and therefore includes dream incorporation. This would suggest a modification to Wright and Koulack to the effect that in addition to benign stressors resulting in non-incorporation and potent stressors resulting in incorporation, *extreme* potent stressors may also result in non-incorporation: which in this case is synonymous with repression. As Walker (2009) notes, post-traumatic stress disorder (PTSD) may constitute a malfunction of the decoupling of memory and emotion process; in which case, repression may be the only viable coping mechanism. Punamäki (2007) notes that dream recall may either increase or decrease after traumatic experiences, perhaps again illustrating that different methods of coping may be used by different people according to the situation and individual.

Similarly, studies have shown that the content of traumatic dreams varies depending on the type of trauma experienced and the stage of recovery. Regarding the type of trauma experienced, it has been found that traumatized individuals with direct military experience of war have more direct, unambiguous, and replicative dreams of their experiences, while traumatized civilians have more indirect, 'symbolic,' and non-replicative incorporations (Schreuder et al., 1998, 2000). Thus, stressors of all levels of intensity may lead to incorporation but those with lower levels may be harder to detect because they are symbolic. Regarding the stage of recovery, Hartmann (1996b), Wilmer (1996), both working with Vietnam veterans, found that there were three types of traumatic dreams experienced by these individuals: apparently veridical replays of war experiences; variable nightmares that pictured plausible scenarios that did not actually occur; and hallucinatory nightmares that were like 'ordinary' nightmares, including material from the previous day. These three types of nightmares were believed to be sequential and indicated stage of recovery: as the trauma of war was adapted to, the dreams become less veridical and more like ordinary dreams (that is, bizarre and symbolic). These studies again show that dream incorporation of, and adaptation to, highly stressful experiences is dependent on various factors, including type of stress and stage of recovery. Hartmann's and Wilmer's suggestion that dreams are repetitive but become more bizarre as recovery is made may be empirical evidence for the aforementioned assertion of many of the theories that the process is long-term and iterative.

While many of the emotion-processing theories suggest, with Walker (2009), that PTSD dreaming is a malfunction of the 'normal' dreaming process (such as Hartmann, 1996b) and account for the change in dreams and adaptation to the trauma by postulating the dreamwork as a long-term, iterative process, they do not attempt to explain what it is that has malfunctioned: why dreams become repetitive and literal, and therefore unable to serve their emotional memory-assimilation process. We address this issue in Section "The Emotion Assimilation Theory of Sleep and Dreaming," where we suggest that PTSD dreams are a malfunction of the 'normal' dreaming process due to the stunting of imagination, which is the driving force of the quality of dreams (such as bizarre, hyperassociative, and metaphorical) required for 'normal' dreaming, which involves the assimilation of emotional memories.

Taken together, the existing theories of emotion processing in both sleep and dreaming share the view that emotion acts as a marker of the importance of an experience, signifying the need for further processing. The reasons for such processing and the mechanisms underlying it have been disputed. We next attempt to synthesize the evidence from both the sleep- and dream-processing fields, in proposing a new theory of emotional memory assimilation during sleep, as evidenced by dream phenomenology.

The Emotion Assimilation Theory of Sleep and Dreaming

In line with sleep and memory researchers (e.g., Payne, 2010; Wamsley and Stickgold, 2011), we propose that emotional waking-life memories are preferentially activated during sleep, thus appearing in dreams, in order to assimilate these memories into the wider memory system. This serves several purposes: (i) consolidation, which is the strengthening and stabilization of the memory (with emotional memories preferentially selected); (ii) assimilation into the memory system, which is the integration of new memories with past memories, expectations for the future, and imagination; (iii) the creation of abstractions and generalizations from the memory; (iv) the generation of creativity, insight, novel ideas, and also problem-solving; and (v) emotion amelioration.

The process differs depending on the type of situation, the stage in which the process is in, and according to individual differences. Adaptation is something that *may* occur as a product of incorporation and assimilation, but this will vary depending on trait differences, the type of waking-life experience, the intensity of the associated emotionality, the wider situation the individual is currently in, their history, the content of the dream, and probably many other factors. Thus, though some kinds of incorporation have been shown to relate to adaptation, in some individuals such as those who score highly on the personality trait 'neuroticism,' incorporation may lead to further emotional unbalance rather than adaptation such that waking-life emotions affect dream emotions and dream emotions in turn affect waking mood. Similarly in some circumstances, such as trauma, extreme emotions can result in non-incorporation (repression), which is, in this situation, necessary for coping. Additionally incorporation may only relate to adaptation when dream content contains specific properties, such as time variance instead of being set in the past.

We propose that the process of assimilating emotional waking-life experiences during sleep and dreaming into pre-existing networks and schemas requires imaginational abilities: for sleep and dreaming to achieve this function, individuals must be able to conjure experiences appearing in dreams during sleep in specific ways, as will be explained in the next section. In the immediate term, information that has been encountered during the day needs to be assessed in terms of its importance and potential future use. The vast amount of stimuli perceived and experienced renders this process somewhat arduous, so emotional information and experiences are first and foremost processed. These emotional experiences are activated during sleep, giving rise to a predictable pattern of dream behaviors. Over time, the emotional stimuli are re-activated in slightly different contexts, as part of the assimilation process. This means that they are better remembered in the short term, the associated emotional intensity is reduced over time during assimilation, and the salient information from the experience is embedded into stable networks for effective and rapid retrieval when needed.

For this to happen, information, and experiences need to be activated repeatedly and in a range of manifestations (Lewis and Durrant, 2011; Horton and Malinowski, 2015). We outline the methods by which this occurs, via dreaming, for emotional material in particular. The clearest way of perceiving how this functions in healthy individuals is to look to the malfunction of the 'normal' process: that is, to look at dreams following traumatic experiences. This follows Hartmann's (1999b) argument that the nightmare is the best type of dream to look at when contemplating dream functioning. As discussed earlier, PTSD dreaming involves the literal replaying of the traumatic experience(s) during sleep, and the literalness of the replaying decreases as adaptation increases. Concomitantly the bizarreness and symbolism, and the associativity with other waking-life experiences, increase also. Underlying these abilities to create bizarre scenarios and metaphors and to make associations between disparate memories is the ability to imagine and to create novel thoughts, and this is the crux of the process. When a person experiences a trauma, their ability to imagine is stunted: not only are PSTD dreams literal rather than bizarre and symbolic, but waking-life imaginational abilities are diminished as well, such as the appearance of more general, and less specific, autobiographical memories (Moore and Zoellner, 2007), including when for when imagining the future (Brown et al., 2012). Furthermore, therapeutic treatments that aim to kick-start imaginational abilities such as Image Rehearsal Therapy (e.g., Krakow et al., 2001) and Focusing-Oriented Dreamwork (Ellis, 2013, 2014) have been shown to reduce PSTD nightmare occurrence and PTSD symptoms.

The more usual (non-clinical) types of repetitively dreaming of the same concern – recurrent dreams and repetitive dream themes – indicate a similar but less heightened malfunction of the 'normal' dreaming process; i.e., the experience is not adequately assimilated into the memory system and so is activated over and over again until assimilation is achieved (e.g., Domhoff, 1993; Zadra, 1996; Hartmann, 1998). This is the view also of Levin and Nielsen (2007, 2009) who argue that recurrent dreams are an example of disturbed dreaming, and are a malfunction of the healthy dreaming process. PTSD nightmares and recurrent dreams are variously perceived by researchers either to be an extreme version of normal dreaming (e.g., Domhoff, 1993), or a failure of the normal dream process (e.g., Hartmann, 1998; Levin and Nielsen, 2007, 2009); however, if the trajectory of PTSD dreams is considered, it can be seen that both of these positions are possible: initially the PTSD dream is a malfunction of the normal dream process in that it repetitively fails to be assimilated, but as the trauma is adapted to the dreams change to become more like 'normal' dreaming, and so in this sense can be seen as being at the extreme end of the spectrum of dreaming, and that end-of-the-spectrum is synonymous with a failure of the process.

The imagination abilities that are required for 'normal' dreaming and which are greatly reduced following trauma, include (but likely are not limited to) the ability to generate metaphors, and the ability to make wide associations between disparate memories (hyperassociativity), which, during sleep and dreaming, are lived, immersive experiences engaging the whole body. These two aspects of imagination are evidenced in dreaming, and, moreover, there is evidence that these kinds of thinking during sleep are associated with the type of creative thinking required to problem-solve and adapt to experiences. In the following section we consider each of these imaginational abilities in turn.

Metaphors

Metaphors ("statements of non-literal reality": Tourangeau and Rips (1991, p. 453) for waking life in dreams are often acknowledged to exist but rarely studied in dream science owing to the extreme methodological difficulties in broaching the subject (e.g., Bulkeley and Kahan, 2008). Nevertheless, many of the world's leading researchers historically and currently subscribe to the notion that dreams can be metaphors for waking life, picturing waking-life experiences and emotions in non-literal, figurative ways (e.g., Jung, 1948a,b; Lakoff, 1993; Hartmann, 1996a; Domhoff, 2003). Some common agreements between researchers exist, including: dream metaphors picture abstract concepts in concrete terms; these metaphors are specialized to the dreamer and thus to understand the metaphor it is necessary to elicit the input of the dreamer; and emotions guide the metaphorical imagery of the dream (e.g., Freud, 1900; Jung, 1948a; Hall, 1953; Lakoff, 1993; Hartmann, 1996a, 1999a,b; Kunzendorf, 2007).

Evidence of Dream Metaphors

To take an example from research, in an interview study we discussed with participants many aspects of dreams that were metaphors for their waking life, such as one participant's dream of the 'Starship Enterprise' taking off from Earth representing her new entrepreneurial career 'taking off,' and another participant who dreamt of a demon being released as representing the release of his own 'inner demon' (Malinowski et al., 2014). These dreams conformed to the three agreed elements of dream metaphors above: they concretely pictured something abstract from waking life; they were about emotional aspects of their life; and it was necessary to talk in detail with the dreamer about what was going on currently in their life in order to understand the metaphor. Among some other of the more convincing dream metaphor anecdotes in dream research are dreams that clearly figuratively reference some waking-life intrusion during sleep, such as the snake coiling round a participant's leg in their dream while a pressure cuff was being inflated around their leg (Nielsen et al., 1993), and the participant who dreamt of a bee making a nest in her hair while she slept with EEG electrodes stuck in her hair (Strauch and Meier, 1996).

In addition to these, studies that make use of inductive qualitative methods and follow these up with quantitative methods (blind content analysis) can demonstrate metaphors in dreams. Bulkeley and Bulkeley (2005) noticed that among a group of individuals diagnosed with terminal illnesses dream content often referred to a journey, which the authors inferred was a metaphorical representation of the journey toward death. Some years later in an unrelated study, Bulkeley (2012) found while blind coding a series of dreams that there were an unusual number of transport dreams, and from this and other clues estimated that they came from a similar group of people; the dreams were indeed from a group of older palliative care patients.

Functions of Metaphor Generation: Novelty

Metaphor theorists have considered the various ways in which metaphors work: for example, they may simply emphasize the similarity between two things; or, alternatively, they may enable something *new* to be discovered from the comparison (Tourangeau and Sternberg, 1982). Tourangeau and Rips (1991) provided evidence for the latter: metaphor creates an *emergent* feature from two previously unrelated things, rather than simply emphasizing their similarities. Similarly Lakoff and Johnson (1980), who instigated the current understanding of the ubiquity of metaphor in our conceptualization of ourselves and our world, discussed non-conventional metaphors, ones that are not already in existence and common usage, and noted that they are 'imaginative,' and 'creative,' and can provide new understandings. This is perceptible in dream metaphors: for example, the condensation into one character of a dreamer's father and male lover, which enables the dreamer to perceive something about the lover that previously they did not (Hartmann, 1996a).

Kuiken (1999) similarly argued that the unidirectional method of interpreting dream metaphors ('A' in the dream represents 'B' in waking life) is erroneous, and that dreams should be interpreted rather as a composite image, in which A says something about B, and B also says something about A. In this argument also there is an emphasis on novelty, on the combination of two loosely related concepts to produce something new that says something about them both. Indeed, it was found in one study that metaphors created from dream imagery were more novel than those generated from waking fantasy imagery, supporting the novelty-producing concept of dream metaphors (Kuiken and Smith, 1991).

Metaphors and Embodied Cognition

The idea of dreams concretely picturing something abstract from waking life does not, however, necessitate that the dream is non-literal, like a spaceship taking off representing a career taking off. Sometimes the concrete representation may be exactly literal, but the way in which it turns the abstract into the concrete is by embodying the thought and making it exist on a physical (albeit imagined) plane. As Hall (1953) wrote, dreams make the conceptual perceptual; and that percept might be a metaphor, but equally it might not be. In their book, Hall and Nordby (1972) discuss the difference between dreams that are 'denotive,' that is, the dream imagery stands directly in for its referent, and dreams that are 'metaphorical,' in which the dream imagery stands in for something less obvious, and may express complex, even contradictory ideas. Denotive dreams do not require any kind of 'decoding' to understand their waking life referent, whereas metaphorical dreams do. Following the logic of the dream and metaphor theorists cited above, it is the metaphorical dreams rather than the denotive dreams that facilitate the making of new connections, the generation of novel ideas. However, it is likely that dreams do not exist in this binary way, denotive versus metaphorical, but that this would be better conceptualized as a continuum. This idea that dreams are embodied simulations of thoughts has been championed by many researchers, such as Domhoff (2011b). In one study he shows how the dreams of a widower about his wife concretely picture his emotional journey after her death (Domhoff, 2007).

Lakoff (1993) notes that metaphors are imagistic – they use imagery from the physical world to conceptualize its more abstract parts – but when used in language they are only pictorial in theory. We do not picture the mental image of someone's feet being cold when we talk about having "cold feet" before a wedding. However, when dreams use metaphors, they *are* imagistic; dreams are visual, but even more than this they are experiential; they are felt, bodily experiences. Many dream theorists have highlighted the experiential aspect of dreaming, such as Jung, Rogers, and Gendlin, as discussed in a recent article by Ellis (2014). In her work, Ellis shows how re-entering and bodily experiencing a dream can enable the dreamwork to move forward, perhaps by empowering the dreamer to "manipulate their internal imagery system." There are parallels here between this Focus-Oriented Dreamwork (FOD) and Gackenbach's findings that high-end gamers seem to have a defense mechanism in their dreams whereby when they have dreams of being attacked they are able to respond in kind because they have rehearsed this behavior in waking life (Gackenbach et al., 2011, 2013). What FOD clients and high-end gamers have in common is that they have rehearsed their adaptive behaviors during wakefulness in lived, bodily, immersive experiences, which then translate into their dream behaviors. Thus, the embodied, lived experience of the imagination is crucial.

Functions of Metaphor Generation: Assimilation

Through dreaming embodied metaphors, which are guided by waking emotions, the dreamer is able to assimilate current waking experiences into their wider memory system, and into their mind as a whole. This is the assimilation process: not only are the experiences reactivated in a memory consolidation fashion, but they are lived in the body through imagination and in this way assimilated into information already stored in the brain. This assimilation process is mostly clearly perceived in the research conducted with PTSD patients as discussed earlier. That is, PTSD involves emotional trauma, a general stunting of imagination, and thereby the literal replaying of that trauma during dreaming; recovery from PTSD involves a gradual move into metaphoricalness in dreaming. Dreamwork such as IRT and FOD involves using imagination to change the PTSD nightmares.

Hartmann (1996a, 1999a,b) suggested that dreams are all "explanatory metaphors" for some waking-life emotion, and that this is most obvious in extreme cases such as PTSD and nightmares; 'normal' dreams also do this but it is much harder to discern the underlying cause. He also showed that daydreams become *more* metaphorical the more emotional they are, becoming like night dreams (Hartmann et al., 2002–2003). This may at first glance seem at odds with the data that show that dreams become more metaphorical the more adaptation occurs after a trauma in individuals with PTSD; but if the latter is viewed as the extreme end of the spectrum, as a malfunction of the process, it may be speculated that metaphoricalness and emotionality increase together up to a point, but if the emotion is so intense that it becomes traumatic then the ability to produce metaphor fails and is lost, because PTSD stunts imagination. Indeed, we found a large positive correlation between the self-reported emotional intensity and metaphoricalness of late-night dreams ($r = 0.50$), and a medium one in early night dreams ($r = 0.35$; Malinowski and Horton, 2014b). If we interpret these findings in line with the emotion assimilation theory, emotion and metaphor increase together because metaphor generation is a tool for imaginatively thinking about important experiences, and emotion denotes importance. Kunzendorf (2007) noted that one of his participants, who intensified the emotion in a reinterpretation of her dream, in so doing gained insight into it. The intensification of the emotion led to insight. The relationship between metaphor and insight is the focus of the next section.

Functions of Metaphor Generation: Insight

Dreamwork often relies on the concept that dreams enable us to find out something about ourselves that we don't already know (Ellis, 2013); this makes sense in light of the evidence that dreams can be metaphorical, and that metaphors generate novel thoughts. This view, however, is in stark contrast to the beliefs of some researchers who claim that dreams *never* tell us anything we don't already know (e.g., Hobson in his dialog with Schredl: Hobson and Schredl, 2011). The difference perhaps rests on differing notions of what dreams 'are': the self-organization of random neural firings in the brain (e.g., Kahn and Hobson, 1993), or the self-organization of meaningful, purposeful, patterned firings of pieces of information with a tendency toward emotionality that the dreamer is not aware of but that would be useful to be aware of. Thus it is necessary to define what is meant when we say "something we don't already know."

Creative insight is defined as the association of elements of information already stored in the mind into new configurations that are in some way useful (Cai et al., 2009). In Cai et al.'s (2009) study, the ability to discover associated words in the Remote Associations Test was significantly enhanced by REM (but not NREM) sleep, when the participants had (unknowingly) been primed on the answers before sleep. Thus REM sleep facilitated this associativity ability during subsequent wakefulness. Sleep processes – and we would argue, the concomitant subjective experience of dreaming – enabled the hyperassociativity of the information that was already stored to be used in a creative and useful way. Similarly, working with dreams has been shown to generate insight into the self (Edwards et al., 2013, 2015), and more insight is obtained when participants are asked to make associations between the dream images and waking life than when simply richly describing the dream images (or a combination of the two: Hill et al., 1998). Perhaps then the idea of dreams telling us "something we don't already know" should be restated as "something we are not aware of knowing," in which 'knowing' may constitute formerly disparate pieces of information that require reconfiguring to become useful. Dreamwork facilitates obtaining insight into these non-conscious thoughts, perhaps through the unraveling of dream metaphors, which, as discussed, are potentially particularly useful for making new discoveries. However, the concept that 'decoding' dream metaphors can enable the generation of insight currently lacks empirical evidence, so this idea is very much speculative at present.

Thus we believe that, despite the difficulties in objectively demonstrating the existence of metaphor in dreams, there is evidence enough to make the assertion that abstract waking-life thoughts appear in dreams in concrete ways; sometimes this concrete representation is 'denotive,' that is, a literal representation, and other times it is 'metaphorical,' that is, a non-literal representation (and variations in between these two states). These metaphorical representations are guided by emotions, enable the assimilation of emotions, and have the potential to generate novel insights, the uncovering of which can be facilitated by dreamwork. PTSD dreams are an extreme or a malfunction of this process, and so are not metaphorical at all, until the recovery process begins, which may be offset by 'kick-starting' the imagination through types of dreamwork specifically designed for this purpose.

Hyperassociativity

The intense connectivity between loosely associated memories ('hyperassociativity') that may be behind insight and creativity during sleep is the second kind of imaginative activity that occurs particularly during sleep/dreaming, and it is to this that we now turn. There is wide agreement among researchers that dreaming, unlike focused waking thought, is hyperconnective, fluid, and flexible (Antrobus, 1993; Globus, 1993; Montangero, 1993; Hartmann, 1996a; Cai et al., 2009; Levin and Nielsen, 2009; Walker, 2009; Walker and Stickgold, 2010; Cartwright, 2011; Llewellyn, 2013). It has something in common with daydreaming and other loose modes of thinking during wakefulness but is more extreme than them (Hartmann, 2010; Fox et al., 2013), and also with the 'default network' of the waking brain (Domhoff, 2011a). Many researchers agree that the dream is always a novel creation, and is often bizarre because of its intense interconnectivity (Montangero, 1993; Hartmann, 1996a; Stickgold and Walker, 2004; Cartwright, 2011).

Evidence of Hyperassociativity in Dream Content

In Stickgold and Walker's (2013) triage theory, it was suggested that once memories have been selected for incorporation, two main processes then occur during sleep: item integration, in which newly learnt memory representations are assimilated into pre-existing schemas; and multi-item generalization, in which new items are combined into a *new* schema. It is this latter process that is particularly of relevance here: this multi-item generalization stage may be reflected in dreams as hyperassociativity. At this subjective, dream level, hyperassociativity is reflected in at least three ways. First, dreams do not replay waking-life experiences 'intact' but rather incorporate them in fragmentary ways, with disparate elements of waking life appearing in one dream narrative (Fosse et al., 2003; Malinowski and Horton, 2014c; Horton and Malinowski, 2015). One study found that 81% of dreams contained abrupt and complete changes of dream events within the dream narrative (Montangero, 2012). During this hyperassociative process, episodic memories are "unbound" or "disconnected" (Payne, 2010, p. 122). The second way in which dreams reflect hyperassociativity is in their bizarreness: disparate, disjointed elements of memory join (associate) together with imagination to form bizarre narratives (e.g., Revonsuo and Tarkko, 2002; Levin and Nielsen, 2007; Montangero, 2012).

The third potential way in which dreams are hyperassociative is in time variance: dreams interweave elements of the past, the present, and the imagined or anticipated future. For instance, Cartwright et al. (1984) found that depressed divorcees had dreams that were often stuck in the past, whereas non-depressed divorcees' dreams exhibited more time variance. Given that many of the theories discussed so far have proposed a mechanism whereby current information is interweaved during sleep with pre-existing information, including 'gist' memories as well as more specific memories (e.g., Breger, 1967; Walker and Stickgold, 2010), it makes sense that dream content that is related to a heightened ability to assimilate this information (and therefore cope with it) exhibits time variance. At the other end of the spectrum are individuals whose ability to assimilate information has been enormously reduced, such as PTSD patients. One of the effects of PTSD symptomatology is the appearance of more general, and less specific, autobiographical memories (Moore and Zoellner, 2007), and this 'overgenerality' has been found to apply also when imagining the future (Brown et al., 2013). Additionally, PTSD patients who were manipulated to believe they were high in self-efficacy were found to generate memories and imagined future events with greater specificity than those who believed they were low in self-efficacy (Brown et al., 2012). This, and the evidence from Cartwright's study in the previous paragraph, indicate that time variance, as one mode of hyperassociativity, is crucial to memory integration and emotion assimilation.

Several studies evidence that dreams respond associatively to waking-life stimuli. Davidson and Lynch (2011) found that, after exposure to a video depicting the events of 9/11, participants had more dreams of material that was literally, closely and loosely related to material, demonstrating the hyperassociative pathways active during dreaming. Similarly, naturalistic post-9/11 studies generally found little evidence for direct incorporations of the event into dreams, but did find evidence for associated images, themes, and emotions (e.g., Hartmann and Basile, 2003; Hartmann and Brezler, 2008). Domhoff (1993), in commenting on the resurgence of traumatic dreaming of Vietnam veterans during much later times of unrelated stress (such as marital difficulties), suggested that the dreams could be metaphorical representations of the present stress; conversely, perhaps the current stress simply opened up associative pathways. Similarly, post-traumatic nightmares can be triggered by a new life event or even a television image up to 40 years after the traumatic experience (Schreuder et al., 1998; Schreuder et al., 2000). Given that it is unlikely that a traumatic nightmare is a metaphorical representation of a television image, it seems more likely that associative pathways to the traumatic experience were re-opened by the associated image.

The fact that dreams involve elements unknown to the dreamer (such as characters or activities that the dreamer has not had direct experience of in waking life) is not evidence against the notion of these being distant memory associations, because memory consolidation does not involve merely strengthening memories for literal recall, but also extraction of the gist of the memory (Wamsley, 2014). Indeed, we have found that 'generic' elements occur frequently in dreams, such that people dream of recognizable 'types' – which come from an amalgamation of a variety of specific waking-life memories, but not any one particular memory – which are akin to 'extras' in a film (Malinowski et al., 2014). For example, one participant dreamt of a generic bookshop and a generic bookshop assistant, which comes from a combination of various experiences of bookshops and bookshop assistants, but without being any particular place or person from memory. Strauch and Meier (1996) call such generic elements the "building blocks" of dreams.

Functions of Hyperassociativity: Assimilation

Many of the researchers cited in Section "Emotion-Processing Theories of Dreaming" who postulated emotion-processing theories of dreaming hypothesize that this process occurs via hyperassociativity (e.g., Breger, 1967; Hartmann, 1996a; Levin and Nielsen, 2007; Cartwright, 2011). Breger talked about the dream providing a context in which mnemonic information is more freely available to be accessed than during waking; and moreover, it is available to be accessed in a fluid, associative manner. This "creative opening up of the memory systems" (p. 25) is what enables integration of new with old memories. Llewellyn (2013) postulates that recent episodic experiences are hippocampal-dependent and are assimilated into long-term, more stable emotional memory networks during dreaming. Thus dreaming provides a context in which experiences can be *elaborated*, activating relational memories. Hartmann (1996a) drew similar conclusions, envisaging the brain as an interconnected network of units, and suggesting that the flow of information between these units during waking (especially during directed thought) is linear, and this is most functional when we are in pursuit of a goal. However, during dreaming, the flow of information is non-linear, and may spread laterally into units that are more loosely connected together; this process is guided by emotion. Thus, PTSD dreams are a dysfunction of this process, and are not hyperconnective but are still guided by emotion, whereas 'normal' dreams following trauma are hyperconnective *and* guided by the emotion. As the dreams move from traumatic to normal, they become more hyperconnective, and thus the original emotion becomes harder to determine. This process contextualizes the current emotional concern in a different (novel) perspective, and in situations that have been experienced before. In this view, new material is interweaved with older material to form new creations, in order to adapt to experiences.

Functions of Hyperassociativity: Insight

These processes are envisioned to occur primarily during REM sleep, the stage of sleep most conducive to hyperassociative thinking. In addition to Cai et al.'s (2009) findings (see Functions of Metaphor Generation: Insight), a number of other studies evidence that REM sleep facilitates hyperassociative thinking, which may lead to insight. Stickgold et al. (1999) found that weak priming (e.g., 'crime' with 'gun') exceeds strong priming (e.g., 'hot' with 'cold') after REM sleep, suggesting again that hyperassociative thinking is occurring during REM sleep. Walker et al. (2002) found that participants awoken from REM sleep were better at solving anagrams than those awoken from NREM sleep, again demonstrating that REM sleep is conducive to associative modes of cognition. Recently, Carr and Nielsen (2015) have shown that a REM-sleep group of participants scored higher than NREM or wake groups on primed emotional stimuli using the associational breadth method. Some behavioral paradigms have demonstrated the overall role of sleep, as opposed to wake, in enhancing insight into associations between learned categories (Ellenbogen et al., 2007). Taking the evidence together, memory researchers posit a complex picture of the brain during sleep; far from mere consolidation (strengthening) of memories during sleep, the brain is undergoing a whole host of memory *transformation* processes, including assimilation and integration, abstraction and generalization, selective extraction of useful information, and generating insights from the information stored (Payne, 2010; Walker and Stickgold, 2010; Llewellyn, 2013).

In Section "Metaphors and Embodied Cognition" and "Functions of Metaphor Generation: Assimilation" it was postulated that metaphor generation may be instrumental in the novelty- and insight-producing abilities of dreaming. Similarly hyperassociativity has the potential to produce novelty and new insights. Kuiken and Smith (1991) suggest that new meanings are reached in dreams during 'visual reorientations': things changing appearance, sudden scene shifts, the dream self suddenly realizing something, etc.; things that often typically make up the categories in content analysis of dream bizarreness (e.g., Revonsuo and Salmivalli, 1995). This bears relation to White's (2014) findings on counterfactual thinking in dreams: he found that when the dream self attempts to solve a problem within a dream, they usually fail. However, when new information just 'appears' in the dream – which can be in the form of a character suddenly appearing, or new knowledge suddenly appearing in the dream self's mind, or any other sudden change – this usually helps to move the dream self forward.

Both Kuiken and Smith's (1991) and White's (2014) research can be interpreted as further evidence for hyperassociativity in dreams. The sleeping mind already has the information required to move the dream forward or come to novel understandings, and this information seems to just 'appear' in the dream because an associative network has suddenly been activated during sleep; the subjective experience of this is a sudden appearance of a person or a thought. The importance of the sudden appearance of something new in a dream is also echoed by Ellis (personal communication) in relation to PTSD dreams: "[a PTSD nightmare] repeats and repeats until something new or different happens that can move the process forward as intended." These sudden openings to associated information stored somewhere in the brain may be behind the insight that is generated during REM sleep. Research is needed to find out what the subjective experience is behind such insights, but it may be that it is these sudden changes in dreams, reflecting sudden 'firings' of associative networks.

The Relationship between Hyperassociativity and Metaphor

Closely related to the idea of hyperassociativity and creativity are the ideas of connectionism and self-organization. Like Hartmann (1996a), dream connectionist theorists such as Globus (1993) discuss the mind as a network of interconnected 'nodes' (neurons) that operates under a parallel processing system, spontaneously reorganizing the entire make-up of the system in response to input. Relatedly, Antrobus (1993) argues that memories for things like attributes, objects, and events are stored as a distributed pattern, which are connected by conceptual similarities. When a unit has a similarity another unit, those units have an active, connected relationship (such as 'leg' and 'flexible joint'), but when they are incompatible with another unit, they have an inhibited, disconnected relationship (such as 'leg' and 'rigid'). Units with such shared conceptual features may be more likely to be connected during dreaming, which enables dreams to be representative or "metaphoric" (p. 81) in quality.

In this view, associativity and metaphor go hand-in-hand during sleep/dreaming; thus there should be a relationship between metaphor and bizarreness, if bizarreness is a measureable marker of hyperassociativity. We found a very large positive correlation between self-reported metaphoricalness and bizarreness in participants' late-night dreams ($r = 0.72$) and a large positive correlation in early night dreams ($r = 0.51$; Malinowski and Horton, 2014b). Similarly, since we argue that the emotion-assimilation function of dreaming is predicated on imaginational abilities, and that dream bizarreness (for hyperassociativity) is one of these abilities, it would be expected that bizarreness and emotional intensity are also positively correlated. There were medium-to-strong positive correlations between emotional intensity and bizarreness in both late-night dreams ($r = 0.46$) and early night dreams ($r = 0.38$). Future research should look into whether these correlations are particular to positive or negative emotions, to throw further light onto whether it is particularly negative emotions that are required to be assimilated via the imaginational properties of dreaming, or whether positive emotions are equally dreamt of in this way.

Temporal Effects of Hyperassociativity

Hyperassociativity may also be evident as a long-term, iterative process, as has been discussed, and illustrates how dream incorporation and adaptation occur after the new emotional experience has been activated, both across multiple nights and within a single night. Blagrove et al. (2011a,b) have replicated the findings of Nielsen and Powell (1992) regarding the dream-lag effect: that is, waking-life experiences tend to appear in dreams the night immediately after they have occurred, and then not again until 5–7 days later; but on second appearance, the dream incorporates the experience in a more abstract way. This could be evidence for the experience being interweaved into the wider memory system, i.e., connections being made between the new information, established information, and imagination. More recently, van Rijn et al. (2015) have found that the dream-lag effect only exists for personally significant events, and not major daily activities or major concerns. This is important because 'personally significant event' implies emotional in both positive and negative ways, whereas 'major daily activities' implies everyday, neutral experiences, and 'major concerns' implies specifically negative thoughts and experiences.

Within a single night, several stage of sleep and time of night effects have been found in dreams: REM dreams and those toward the end of the night tend to become longer, more vivid, more emotional, and more bizarre (Hobson et al., 2000; Wamsley et al., 2007; Malinowski and Horton, 2014b), although REM and NREM dreams become more similar as the night progresses (Nir and Tononi, 2010). Similarly Wamsley et al. (2010) found that incorporation of waking life experiences increased in abstraction with duration of sleep. Cartwright also found (Section "Cartwright: The Emotion Regulation Function of Dreaming") that dreamers who achieve emotional adaptation tend to start out dreaming in negative tones in the early night and end up in positive tones in the late night. Thus a picture begins to build for dreaming across the night, where bizarreness, emotional intensity, and emotional valence change as the night goes on. More research is required to get a fuller picture of these changes, considering metaphor also (Malinowski and Horton, unpublished manuscript).

Similarly, time of night influences memory consolidation during sleep, such that episodic memories tend to be preferentially consolidated during NREM sleep in the earlier portion of the night, and procedural and emotional memories during REM sleep in the later portion of the night (Plihal and Born, 1997; Payne, 2010). Such evidence has led some researchers to propose a memory consolidation theory of sleep whereby slow wave sleep (SWS) initially consolidates recent episodic material (such as from the previous day), and REM sleep integrates and abstracts it (e.g., Giudatta et al., 1995, see also Llewellyn, 2013). Such theorizing is in line with the dream research findings, since early night (SWS) dreams tend to reflect current concerns, and later night (often REM) dreams tend to be more bizarre, which may mean they are more hyperassociative, as above. This in turn may reflect the subjective experience of the memory integration function of REM sleep. Whilst we recognize that dreams from late-night sleep are typically more bizarre than those elicited from early night sleep, we are not in a position to postulate that the emotion assimilation processes are specifically REM-dependent. Rather, they may require both non-REM and REM processing (Ellenbogen et al., 2007; Cairney et al., 2014), or be a function of time spent asleep.

At the chemical level, these time of night changes in hyperassociativity may be understood as a function of the circadian cycle of the stress hormone cortisol (Payne, 2010). Traumatic experiences, which are accompanied by the release of cortisol, are often fragmented and lack coherence, with little episodic or contextual information retained. Conversely, emotional material is 'stamped in'; the resultant effects are either disjointed memory fragments, or memories that undergo "narrative smoothing" (p. 117), the latter of which is similar to the synthesis of memory fragments into a narrative in dreams. Thus, since levels of cortisol increase across the night and peak in the late morning, so dreaming becomes more fragmented and bizarre across the night, peaking in the late morning.

Hyperassociativity during sleep/dreaming, then, appears to index one of the stages of memory consolidation during sleep: that is, the stage during which memories are integrated, which happens during late-night, predominantly REM, sleep. During this stage of the memory consolidation process, recent memories are activated and associated with other information already stored in the memory system. There is widespread evidence for hyperassociativity occurring during sleep, such as the insight generated following REM sleep compared to NREM and wakefulness; likewise there is widespread evidence for hyperassociativity during dreaming, such as time variance in dreams, the activation of associated memories following exposure to stimuli, and the fragmentariness and bizarreness of some, particularly late-night, dreams. Several researchers conceptualize the mind in this state as a series of interconnected nodes, activating in parallel rather than the more sequential, or linear, mode of thought common to focused waking cognition. Hyperassociativity, like metaphor, has the potential to create novel insights. It increases over time, both within a single night (bizarreness increases toward the end of the night and episodic replayings of memories decrease; this may be seen at the chemical level in increases in cortisol), and across many nights (abstraction increases with repeated incorporations, as evidenced by dream-lag studies).

Suggestions for Future Directions

As we have emphasized throughout, theories of emotional processing during sleep could benefit from exploring dream content, and theories of dreaming could benefit from considering the behavioral and neurological profile of the sleeping brain. In practice empirical studies from the sleep lab need to be followed up with dream studies. Dreams can be studied as transparent reflections of sleep-dependent memory processes (Wamsley, 2014), provided they are sampled under ideal conditions (Windt, 2013), taking heed from the systematic and rigorous methodologies typifying sleep science (Kahan and Horton, 2012). More specifically, there are some aspects of our proposed emotion assimilation theory that would benefit from greater exploration. The time-course of the emotion assimilation processes is as yet understudied, with the domains of sleep science and dreaming sometimes focusing on different levels of enquiry, with sleep-labs typically exploring shorter time frames, from naps (e.g., Payne et al., 2015) to around 24 h periods (Ellenbogen et al., 2007) compared to some longer-term dream studies (e.g., Cartwright's divorcee studies, Section "Cartwright: The Emotion Regulation Function of Dreaming.") Similarly the role of REM sleep, in particular, requires further consideration in the selection of emotional information, and its subsequent consolidation.

The differential effects of positive and negative emotions in the consolidation and assimilation process should also be parsed out. Kensinger (2009) has reviewed the effects of emotion on (non-sleep-dependent) memory processes, and found that while emotion has a beneficial effect for memory whether it is positive or negative, the benefits are different: positively valenced memories are more likely to be remembered in terms of the gist of the memory, whereas negatively valenced memories are more likely to recalled in specific detail. That is, she found a link between negative emotion and sensory processing on the one hand, and positive emotion and conceptual processing on the other. These effects should be investigated in terms of the effects of differently valenced memories and sleep, and the phenomenology of these effects during sleep by investigating dream content.

Dream science can be particularly insightful in terms of the study of metaphors and associations between memory elements to reflect assimilation. It has been over 10 years since Domhoff's (2003) suggestion that inductive qualitative methods, followed up with objective quantitative methods, are used to study dream metaphors in depth, but few researchers have broached this topic yet. More research is needed to investigate the conscious experiences of assimilation that occur during sleep in dreams, and dream metaphor, hyperassociativity, and bizarreness may provide starting points. Similarly, dream content may be fruitful in the study of other memory processes during sleep, such as gist extraction and insight generation.

Finally, links between dream content and more general memory behaviors are needed, such as exploring dream content from periods of successful consolidation (versus less successful consolidation) and, where possible, identifying specific links between dream content and enhanced recall of those memories activated in dreams (as in Horton, 2012). More generally, exploring the content of dreams taken from sleep that enhances creativity, insight or problem solving may also shed light on the sleep-dependent processes that give rise to such successful cognitive functioning.

Conclusion

We have proposed (i) that emotion acts as a marker for information to be selectively processed during sleep, including consolidation into long term memory structures and integration into pre-existing memory networks, (ii) that dreaming reflects these processes of emotion assimilation, and (iii) that the associations between memory fragments activated during sleep give rise to measureable elements of dream metaphor and hyperassociativity (e.g., time variance and bizarreness). In turn, these elements indicate the time-course of emotion assimilation, with greater bizarreness signifying greater distance from the original emotionality of the experience, in turn indicating more advanced assimilation.

These processes directly compliment the proposed model of autobiographical memory functioning in the sleeping brain (Horton and Malinowski, 2015) which describes how waking-life elements are broken down into fragments, subsequently re-bound together via hyperassociativity during sleep, and manifest in bizarre experiences of dreams and the metaphorical representation of salient and emotional waking life experiences. In our emotion assimilation theory we emphasize how emotion during sleep can function to improve the retention and retrievability of salient experiences so we can make use of them better in the future. Taken together, experiences and information from waking life can be broken down for offline filing during sleep, and activated as part of that process. Associated emotionality of those memory fragments leads to heightened activation, in turn resulting in further hyperassociativity, and as such a stronger memory consolidation process ensues.

Currently there is not enough evidence to make the claim that experiencing dreaming contributes to emotional assimilation directly; rather, dreaming can be taken to reflect the activation of memories whilst the brain's sensitivity to external stimuli is lessened (Murkar et al., 2014). Dreaming provides a methodological tool for exploring cognitive processing during sleep, though at this stage we are not able to measure the additional value of dreaming versus not-dreaming to these processes. (See Kahan and Horton, 2012, for a brief review of dreaming as a methodological tool.) We assume that dreaming occurs in the vast majority of individuals each night during sleep, though being able to remember one's dreams is independent of the sleeping brain's ability to assimilate emotional material into pre-existing networks. Further, although we propose that sleep may serve the function of assimilating emotional information into a stable, organized network of personal and semantic information, we make no claims about this being sleep's only, or even main, function. Similarly, we recognize that sleep has evolved and its primary functions likely changed, with functions such as emotion assimilation being a consequence of a rapidly evolving and stimulated human brain in everyday contexts.

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