Different temporal patterns of memory incorporations into dreams for laboratory and virtual reality experiences: Relation to dreamed locus of control

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Summary. Previous work demonstrates that memories about a target experience are incorporated into dream content according to a U-shaped temporal pattern with a peak of incorporations around 1-2 days following the experience (day-residue effect), a diminution on days 3-4, and a recurrence of incorporations on days 5-7 (dream-lag effect). This temporal pattern has been observed for many types of experiences, but no study has yet investigated either whether the pattern occurs differentially for qualitatively distinct, yet temporally proximal, experiences or whether the pattern also manifests in generic changes that are not specifically related to the target memory. The current study traced memory source incorporation patterns of two qualitatively distinct but temporally overlapping events: a laboratory overnight stay (LAB), considered to be an interpersonal and passive experience; and a virtual reality maze task (VR), considered to be a solitary and active experience. Hypotheses were that: 1) elements of LAB and VR experiences would be incorporated independently and exhibit different temporal patterns of incorporation into dream content; and 2) these incorporation patterns would be associated with different generic changes in dream content, i.e., a primarily external dreamed Locus of Control (Dream LoC) for dreams incorporating LAB experiences and a primarily internal Dream LoC for dreams incorporating VR experiences. Twenty-six participants each spent 1 night in the sleep laboratory, underwent a VR maze task in the morning, and then kept a home dream log for 10 days. Judges rated dreams for evidence of incorporation of LAB and VR experiences. Results were consistent with expectations: 1) LAB and VR experiences showed independent and opposite temporal incorporation patterns; LAB incorporations showed both day-residue and dream-lag effects whereas VR incorporations revealed a peak only on day 4; 2) Dream LoC scores were more external for Day 1 (peak of LAB incorporations), and more internal for Day 4 (peak of VR incorporations). Different incorporation patterns for these two experiences may reflect separate underlying processes of memory consolidation responding to different types of stimulus events. Further, temporal patterning of both specific dream incorporations and general dream content changes (LoC) may reflect qualitatively different aspects of episodic memory consolidation.

Keywords: dream content; memory; day-residue; dream-lag; locus of control; virtual reality

1. Introduction

Accumulating research from both human and animal studies attests to a complex and nuanced role for sleep in memory consolidation (for reviews, see Stickgold & Walker, 2013; Rasch & Born, 2013; Abel, Havekes, Saletin, & Walker, 2013). And even though the hypothesis that dreaming is implicated in these sleep-dependent consolidation processes is frequently proposed (e.g., Payne, 2010; Wamsley, 2014; Stickgold, 2005), there remains a considerable shortage of research supporting this hypothesis and clarifying dreaming's role in memory.

One line of inquiry implicates dreaming in the consolidation of episodic memories, i.e., explicit memories for discrete autobiographic events (Tulving, 2002). Some studies report that episodic memory consolidation is dependent upon REM sleep (Rauchs et al., 2004), the sleep stage during which the most vivid and lengthy dreaming is most likely to occur (see reviews in Nielsen, 2000; Hobson, Pace-Schott, & Stickgold, 2000). Episodic memories are also known to appear in dream content, albeit often in fragmented form (Baylor & Cavallero, 2001; Fosse, Fosse, Hobson, & Stickgold, 2003; Cicogna, Cavallero, & Bosinelli, 1991; Nielsen & Stenstrom, 2005). This may indicate that dreaming implicates the reactivation of mnemonic traces (Paller & Voss, 2004) and, possibly, contributes to offline memory replay and reconsolidation (Wamsley & Stickgold, 2011). Or, it may mean that dreaming serves to recontextualize newly acquired memories by integrating them into

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Submitted for publication: October 2014
Accepted for publication: April 2015

broader autobiographical networks (Carr & Nielsen, 2015). Evidence for such notions is, however, slim. Nonetheless, the finding (Eichenlaub et al., 2014) of a correlation between the incorporation into dream content of elements related to recent experiences and frontal theta EEG activity during the last 3 minutes of REM sleep, supports the notion of a relationship between plasticity-related memory consolidation and dream content. Similarly, the finding of a relationship between incorporations into NREM dreams of attributes of a maze-learning task and subsequently improved performance on that task (Wamsley, Tucker, Payne, & Stickgold, 2010c) supports the same notion. All such studies point to the necessity of evaluating specific relationships between dream content and recent episodic memories. In the present study we investigate temporal relationships between dreaming and episodic memories, in particular, between dreaming and the temporal patterns describing the specific appearance of episodic memory fragments in dream content over several days following exposure to two types of experience: a laboratory stay and a virtual reality (VR) maze task. We also examine the influence of these experiences on generic changes in dream content, in this case, the perceived locus of control (LoC) of influences within the dream content (Dream LoC).

1.1. Temporal patterns of memory incorporation: day-residue and dream-lag effects

1.1.1 Day-residue effect

The notion of day-residue, coined by Freud in the *Interpretation of Dreams* (Freud, Strachey, & Freud, 1958), refers to memory elements in a dream that herald from experiences occurring the previous day; Freud considered such elements to be commonplace, and to serve as 'raw material' for dream formation. Day-residue elements have been observed in many empirical dream studies, including self-observational studies of both morning REM-rich dreams (Hartmann, 1968; Jouvet, 1979) and hypnagogic images (Nielsen & Powell, 1992), and multiple participant studies (Blagrove et al., 2011a; Blagrove, Henley-Einion, Barnett, Edwards, & Heidi Seage, 2011b; Blagrove & Pace-Schott, 2010; Harlow & Roll, 1992; Malamud & Linder, 1931; Nielsen & Powell, 1992; Van Rijn, Eichenlaub, Lewis, Walker, Gaskell, Malinowski, & Blagrove, 2015). Day-residue elements are, in fact, highly prevalent. In one study (Harlow & Roll, 1992) nearly 50% of dreams provided by a college student sample (N=88) contained unambiguous day-residues that were identified by the participants themselves.

Some studies demonstrating the day-residue effect have used general stimuli for tracking memory incorporations, such as presleep suggestions or induction of a particular psychological or physiological state, e.g., thirst (Dement & Wolpert, 1958), hunger (Baldridge, Whitman, Kramer, Ornstein, & Lansky, 1965), social isolation Wood, cited in (Tart, 1965), or hypnosis (Barber, 1962). Other studies have used the relatively specific context of the sleep laboratory as a target stimulus. As many as 22% of REM sleep dreams from a number of different laboratory studies contained unambiguous references to the laboratory situation (Dement, Kahn, & Roffwarg, 1965). Similarly, a literature review (Schredl, 2008) found that direct references to the laboratory appear in from 6.2% to 32% of dreams. Indirect references (e.g., references to any laboratory or experiment) have a much higher incidence, ranging from 32% (Baekeland, 1969) to 68% of laboratory dream reports (Whitman, Pierce, Maas, & Baldridge, 1962).

The day-residue effect may also be a factor in the formation of mentation during NREM sleep, at sleep onset and during Stage 2 sleep in particular. First, a study in our own laboratory (Stenstrom, Fox, Solomonova, & Nielsen, 2012) demonstrated that a trained participant reported 6 day-residues out of 31 sleep onset reports (19%) collected during two nights of multiple awakenings. Second, Stage 2 day-residue incorporations of a maze task were not only readily identifiable, but found to predict improved performance on a task retest (Wamsley, Perry, Djonlagic, Reaven, & Stickgold, 2010a; Wamsley, Tucker, Payne, Benavides, & Stickgold, 2010b). Third, day-residue incorporations into NREM sleep mentation that followed a complex visuomotor task (Alpine Racer arcade game) were found in 30% of reports, with the nature of incorporations changing across the night, from relatively direct, concrete incorporations to more abstract representations of the task (Wamsley et al., 2010a). Fourth, day-residue incorporations of the video game Tetris into sleep onset mentation were so robust that both healthy controls and anterograde amnesiacs displayed them (Stickgold, Malia, Maguire, Roddenberry, & O'connor, 2000). Finally, Tetris video game incorporations were also found in 10% of sleep onset reports, often mixed in with other memory sources (Kussé, Shaffii-Le Bourdiec, Schrouff, Matarazzo, & Maquet, 2012). But, a lack of a day-residue effect for SWS dreams has been reported (van Rijn et al., 2015)

1.1.2 Dream-Lag effect

The term dream-lag was coined by Nielsen and Powell to describe the incorporation into dreams of memory elements for experiences that took place about 6-7 days earlier (Nielsen & Powell, 1989). In the first pair of studies by this group (Nielsen & Powell, 1989; Nielsen & Powell, 1988), participants kept 1-week home dream logs and then retrospectively wrote down their most significant events from that same week. One salient event for each participant occurring early in the week was chosen by experimenters to serve as a target stimulus and was rated by blind judges for its similarity to elements in the dream reports that followed it. Events had higher similarity scores with dreams occurring on days 1 and 6 following the event than with those occurring on days 2 through 5. A second, replication, study used 7-day home dream diaries that were completed by self-reported high dream recallers after they had spent a night in a sleep laboratory. In this case, and similar to the present method, judges rated incorporations of the laboratory situation in dream content. Day-residue and 6-day dream-lag effects were both found. In a third study, both effects were again observed for dream incorporations of an emotionally arousing video, but only for participants who showed at least one high incorporation score. Participants exhibited a day-residue effect on days 1 and 2 and a dream-lag effect on days 5-7 (Powell, Nielsen, Cheung, & Cervenka, 1995). Finally, high levels of incorporation of memories of personally important events were observed to occur preferentially on days 6 and 12 after the experiences in home log dreams (Nielsen & Powell, 1992).

The dream-lag effect was first independently replicated by Blagrove's group in several recent studies. In one (Blagrove et al., 2011b), 8 female participants kept home dream and waking event logs for 14 days and then matched similarities between the two sets of reports. As predicted, matches were higher for post-event days 5-7 than for either post-event days 2-4 or a pre-dream baseline estimate. Emotional and physical engagement in events seem to be important determinants of the dream-lag effect. In one of our studies (Nielsen, Kuiken, Alain, Stenstrom, & Powell, 2004), when asked to identify memory sources for self-selected home log dreams, participants showed high dream incorporation of memories for events occurring on days 1-2 and 5-7, but not days 3-4, prior to the dream; further, memory items most likely to show delayed incorporations were characterized by their interpersonal nature, spatial locations, resolved problems and positive emotions. In a similar vein , a U-shaped pattern consistent with the dream-lag effect was found for incorporations of personally significant events, but not for major daily activities or significant concerns (Blagrove et al., 2014; van Rijn et al., 2015). Another of our studies (Lara-Carrasco et al., 2008) showed that selective REM-sleep deprivation disrupted a U-shaped temporal pattern of incorporations of emotionally negative experiences, i.e., fearful slides that had been viewed prior to sleep. This may mean that REM sleep's role in emotional memory consolidation is a determinant of the temporal pattern of incorporations. This notion was supported by a study (Blagrove et al., 2011a) in which the dream-lag effect was found for dreams elicited from REM sleep, but not for Stage 2 NREM sleep. In a final study by our group, participants who were allowed to actively explore a VR maze incorporated more elements from that maze into their dreams than did participants who only viewed the maze passively (Saucier, 2007); the active group, but not the passive group, exhibited both day-residue and dream-lag effects (Nielsen, Saucier, Stenstrom, Solomonova, & Lara-Carrasco, 2007).

Other small-N studies support the notion of the dream-lag effect to varying degrees. Michel Jouvet, a pioneer in sleep research, noted the appearance of delayed incorporations of travel experiences in his personal dreams (Jouvet, 1979): readily traceable elements of travel to new locations reappeared 7-9 days after leaving on a trip. Similarly, a group of participants who wore red-tinted goggles for several days showed that incorporations of red elements in early night dreams were delayed by 5-7 days (Roffwarg, Herman, Bowe-Anders, & Tauber, 1978). A type of dream-lag effect was also shown in a single participant study (Kookoolis, Pace-Schott, & Mcnamara, 2010) that assessed memory sources for dreams from both NREM and REM home awakenings across 25 nights. This participant's matches between dream elements and home log entries were time- and sleep stage-dependent, with emotions, settings and characters being incorporated earlier (1-2 days) after the experience and events and objects being incorporated later (3-4 days) after the experience.

In sum, a growing body of research has demonstrated that memories of waking experiences are incorporated partially into dreams according to a U-shaped temporal pattern, i.e., both immediately after the experience (day-residue effect) and—with some exceptions—after a delay of about 5-7 days (dream-lag effect). Among the many experimental stimuli that have been investigated for influencing dream content, the laboratory situation has proven very reliable, as have immersive VR tasks. We therefore chose a laboratory overnight stay and a VR maze task as two target waking experiences for which we could assess the temporal patterning of dream incorporations in the present study.

1.2. Rationale for assessing Locus of Control (LoC) in dream content (Dream LoC)

Many kinds of stimuli and personal concerns have been shown to influence dream content. As described above and elsewhere, autobiographical experiences, such as self-selected current concerns (Nikles, Brecht, Klinger, & Bursell, 1998), emotional films (Foulkes & Rechtschaffen, 1964), intentionally suppressed thoughts (Wegner, Schneider, Carter, & White, 1987; Rassin, Merckelbach, & Muris, 2000; Wegner, Wenzlaff, & Kozak, 2004) a VR maze (Saucier, 2007; Nielsen et al., 2007), and, especially, the experience of sleeping in a sleep laboratory (Baekeland, 1969; Schredl, 2008), are all stimuli able to influence dream content. To the extent that such stimuli are specific, discrete and unique, their influence on dream content may be more easily tracked; sleep lab features, film references, and VR maze elements are all specific stimuli that allow detection of specific incorporations in dream content.

In addition to such specific effects, some studies suggest that dreams may also respond to waking experiences with more generic changes. Frequently, dreams will depict the general affective and emotional tone of prior experiences, as in the case of trauma victims who report more intense negative dreams (Helminen & Punamäki, 2008), bereaved individuals who report dreams incorporating the different stages of grief (Belicki, Gulko, Ruzycki, & Aristotle, 2003; Garfield, 1996; Barrett, 1991; Kuiken, Dunn, & Loverso, 2008) or otherwise healthy individuals whose dreams incorporate the general emotional tenor of a pre-sleep film (Kuiken, Rindlisbacher, & Nielsen, 1990). Such general effects on dream content by their very nature are often difficult to operationalize and measure.

We approach this problem by viewing dreaming as due to a simple interplay between two main organizational factors. The first, referred to as the self factor, is conceptualized as the cognitive processes that determine the make-up and actions of the dreamed self-character and its ability to effect change in the dream narrative. The second, referred to as the non-self factor, encompasses the cognitive processes that determine dream features that are external to the self-character yet have agency in effecting change in the dream. These include the representation of other characters, dream settings and even seemingly impersonal events, such as the dream's weather or general atmosphere.

The notion that dreaming employs a two-factor dynamic is not new. Freud insisted that every dream was a combination—a compromise-formation—of two competing influences: affect expression (wish-fulfillment) on the one hand and impulse repression (dream-work mechanisms) on the other. However, whereas Freud did not explicitly link these two general influences to self and non-self factors, more recent theorists have done so. Two (of many) illustrative examples include: a) threat-simulation and fear extinction theories of dream function by which dreaming permits rehearsal of adaptive reactions through the combined dynamic of non-self, threatening situations that present themselves to a self-character who responds appropriately and effectively (Valli et al., 2005; Valli & Revonsuo, 2009; Revonsuo & Valli, 2008); b) research on sleep paralysis (Cheyne, 2005; Cheyne, Newby-Clark, & Rueffer, 1999) during which 'felt presence' experiences of 'someone' or 'something' present in the room causes significant distress to the self-character (Solomonova et al., 2007; Cheyne & Girard, 2007; Solomonova et al., 2008).

As central as the self-character may be to most dreams, its movements in relation to the dream setting and its interactions with other dream characters is also key to dreaming's narrative structure and—possibly—to its function as well. Not only does the self-character encounter and exchange socially with others, but s/he interacts in numerous ways with features of the dreamed environment. Sometimes the latter is responsive and welcoming; other times hostile and difficult to negotiate. Thus, while the self-character is often the primary instigator of events in the dream, the driving force of these events may also be found in non-self sources of different kinds. For example, among the most typical dream themes that have been documented are those at both ends of the self/non-self continuum, i.e., dreams in which the self-character is either 'trying again and again to do something' (self) or 'being chased or pursued' by another character (non-self; Nielsen et al., 2003).

The dynamic interplay between self and non-self sources of agency within the dream can be conceptualized and operationalized as a form of locus of control (LoC) within the dream. Just as real world events can be reliably categorized as effected by primarily internal or primarily external events, so too dream events may be categorized for their predominant source of agency. We consider that the relative influence of internal vs. external sources of agency in dreams may change over time, both within a single dream and across multiple dreams, but we also suggest that individual dreams may be scored globally as being predominantly either internal or external in nature.

In this study, we do not use LoC in its original sense as a stable personality trait, represented by a continuum between perceived internality and externality of agency such that individuals generally judge most of their life events to be driven either by other people, chance, or fate (external LoC), or by their own intentions and actions (internal LoC) (Rotter, 1954). Rather, we have modified the 2-dimensional LoC notion to apply specifically to dynamic dream narratives. Dream LoC here refers to an objective judge's determination of the relative efficacy, control or influence that is exhibited by either the dreamed self-character or non-self sources in effectuating changes in the dream narrative. Dream LoC thus assesses the relative weight of contributions by self and non-self sources of agency in the dream.

The notion of Dream LoC has not been previously used in dream research. However, LoC as a classically defined personality trait has been investigated (Blagrove & Hartnell, 2000; Blagrove & Tucker, 1994).

1.3. Study objectives and hypotheses

For the present study, we treat the laboratory (LAB) stay and the virtual reality (VR) maze task experienced during the laboratory visit as two separate, albeit concurrent, target experiences. We consider the LAB stay to be a predominantly external LoC situation, i.e., interpersonal and relatively passive, during which participants undergo many experimental manipulations, such as having electrodes and other sensors installed, being awakened for dream collection, filling out forms, etc. In contrast, we consider the VR maze task to be a primarily internal LoC situation, i.e., solitary, goal-directed and active, during which participants are alone in a room, equipped with VR goggles, exploring and attempting to find an exit from a virtual maze.

The first objective of the study was to demonstrate day-residue and dream-lag incorporations in prospectively collected home dreams, while tracking the appearance of these two effects as a function of the LAB and VR experiences. The second study objective was to investigate whether, in addition to incorporations of specific experience-related elements, dream content also reacts with generic changes—with shifts in dream LoC in particular.

The two hypotheses corresponding to these objectives were: 1) the LAB and VR situations will be followed by opposing temporal profiles of dream incorporation over the 10 days of the home log, with only the LAB situation producing the familiar U-shaped profile of day-residue and dream-lag incorporations, and the VR stimulus following a delayed U-shaped profile, or an entirely different temporal pattern; 2) these different incorporation profiles for LAB and VR situations will be associated with different dream LoC scores, specifically, a) primarily external dream LoC for dreams high in LAB incorporations; and b) primarily internal dream LoC for dreams high in VR incorporations.

2. Methods

2.1. Participants

Twenty-six healthy volunteers (10 men; 16 women; average age=26.2 yrs; SD=3.7; range=21-34), self-reported to be free of major physical and psychiatric conditions and medications known to affect sleep and dreaming, were recruited by word of mouth and by advertisements. They were made aware that they were participating in a 14-day study of the memory sources of dreaming. Since the daily recording and submitting of home dream reports was a requirement of the study, participants were selected on the basis of having access to a computer equipped with both text editing software and email. Also, to optimize the accuracy of dream reporting and transcribing, individuals were selected according to the following inclusion criteria: 1) self-reported dream recall of at least 3 dreams per week; 2) self-reported English or French language proficiency; 3) ability to type. Levels of linguistic ability and typing were tested during the laboratory visit. Of the 26 participants, 14 were French native speakers, 6 were English native speakers, and 6 reported some other native language but were still proficient in French (N=2) or English (N=4). In total, 16 participants submitted French dream reports and 10 submitted English dream reports. Participants were asked to abstain from consumption of recreational drugs, excessive caffeine, and alcohol for the duration of the study. Participants signed a detailed informed consent form. All received a small monetary compensation upon completion of the study.

2.2. Procedures and Materials

Participants spent one night sleeping in the laboratory, where they had 16-channel surface ECG, EMG, EOG, and EEG electrodes installed according to the norms of the international 10-20 system (Niedermeyer & Da Silva, 2005). All-night polysomnography was conducted, but these results are not reported here. There were no more than two participants present in the laboratory at a time and each slept in a separate isolated room monitored by a video camera. All communication between participants and staff during the night took place through an intercom system. All participants underwent a dream recall and reporting training session prior to sleep (see later). They were allowed to sleep for at least 6.5 hours undisturbed and were then awakened once from the last REM period of the night to report dream content. After this, electrodes were removed, they underwent the VR maze task (see later) and were allowed to leave.

2.3. Training sessions

On arriving at the laboratory, participants were randomly assigned to one of two conditions referred to as the training (TRN) and control (CTL) groups. While seated comfortably on the bed, participants in both groups received the following instructions about how to report their dreams. They were told to pay close attention to their dreams and to reflect on them more than once upon awakening. To give their oral reports, they were asked to first report the 'last 60 seconds' of their dream, and then the 'rest of the dream' that occurred before that. They were then asked to reflect on the specific memory sources of their dreams and to date them. They were allowed to practice these procedures during recall tasks that took place both in the evening and the next morning. In the evening, they viewed and were asked to recall, as if it were their own dream, a short film clip shown on a 19-inch computer monitor suspended in front of them while they were seated on the bed. Second, they recalled hypnagogic dreams from 4 consecutive sleep-onset awakenings. Third, in the morning, they recalled a dream from the last REM sleep period of the night. The TRN and CTL groups differed only on the specific instructions that they received about what attributes of their experiences to attend to during the training . The TRN group was asked to reflect on the perceptual details of their dream, such as the order in which dream elements unfolded, specific bodily movements and details about their inner reactions. In contrast, the CTL group was asked to describe their dreams in as much detail as possible, without any specific order or focus on perceptual determinants. These procedures were part of a larger study of the effects of self-observational training on dream recall, which will not be reported in detail here.

2.4. Home dream logs

Participants kept home dream logs for 4 days prior to the laboratory stay and for 10 days after. All dream reports were completed at home, except for the post-laboratory day 1, which was completed in the laboratory. Participants typed their dreams in the morning using one of two Microsoft Word templates provided for them. For the 4 days of pre-laboratory dreams, the template was the same for all participants and included instructions to first recall and report the 'last 60 seconds' of the dream, and then report the 'rest of dream', as well as to note any memory sources related to either part of the dream. For the 10 days of post-laboratory dreams, the CTL group continued to use the same pre-laboratory template while the TRN group receive a new template that reiterated instructions given to them during the laboratory dream recall training session, including a reminder to recall and report the 'last 60 seconds' of the dream in detail first, followed by the 'rest of dream', and the dream's memory sources.

2.5. Virtual reality maze task

After electrodes were removed in the morning, participants underwent a VR maze task that was programmed in-house using the ATARI Unreal Tournament 3 engine (Epic Games Inc., 2007). The task consisted of an underground maze from which participants were asked to find an exit. To increase the associated sense of immersion, the maze was presented while participants stood in a darkened room wearing Cybermind 900st hi-resolution goggles with an Intersense InterTrax2 positioning tracker and a 5.1 sound surround system (Sony Home Theater System STR-DE985; 6 Acoustic Research speakers). The goggles allowed participants to navigate the VR environment in a relatively realistic way, with life-like head movements producing corresponding changes of visual angle in the maze. A button on a hand-held mouse was used to move forward in the maze. Participants were required to navigate 3 different environments that were connected by long granite corridors: 1) a collection of indoor industrial-style rooms, 2) an outdoor, snow-covered forest, and 3) a second set of indoor spaces. Once through all of the environments, participants were required to 'jump' into a river of lava, an experience that added an aspect of vestibular realism to the task. Average time for completing the VR maze task was 23.2 min. (SD=8.2; min=8.7, max=43.0). Some screenshots of the VR environment are shown in Figure 1.

2.6. Dream scoring and dependent measures

Two bilingual judges, blind to both training condition and whether each log dream preceded or followed the laboratory visit, and familiar with the experimental procedures, the laboratory, and the VR task, scored the dreams for a) type and number of elements of the laboratory (LAB); b) type and number of elements of the VR maze; and c) Dream LoC. The degree of directness of LAB and VR maze incorporations was scored on 3-point scales where 0=no incorporation, 1=indirect incorporation, and 2=direct incorporation. The number of LAB and VR elements consisted of a simple tally of all incorporated elements of each type in each of the two parts of the dream report ('last 60 seconds,' 'rest of dream'). Because preliminary analyses indicated that these two parts of the dream did not differ from each other, incorporation ratings and element frequency counts were summed to produce a total incorporation rating and a total element frequency count. These dependent measures were used in the analysis of incorporation patterns; the 'full dream', 'last 60 seconds' and 'rest of dream' scores were all used in the analysis of Dream LoC scores.

Items considered as belonging to the LAB situation excluded any VR elements but included: the experimenters; the hospital environment; the laboratory environment including PCs, amplifiers, electrodes and related equipment; being a participant in an experiment including being monitored while asleep; and content from the training film clip. Items considered as belonging the VR situation excluded LAB elements but included any features of the 3 maze environments including: snow, lava, rusted metal, corridors, doors, being underground, looking for an exit, and jumping. Participants' descriptions of memory sources of the dream content were also used by judges in scoring of LAB or VR incorporations.

Dream LoC was scored on a 7-point Likert-type scale in response to the following question: To what extent did the events in the dream seem to be determined by either the protagonist (internal), or the dream characters and/or settings (external) or both? Scale anchors were: 1=internal; 4=both internal and external; 7=external. Dream LoC was evaluated separately for the two parts of the dream and combined by averaging the two scores (full dream).

Dream length was also assessed by 2 blind judges using the Total Word Count (TWC) method of Antrobus (1983) to count all words minus pauses, fillers, corrections, repetitions and commentary. Counts were made separately for 'last 60 seconds' and 'rest of dream' parts of the dream; TWC was calculated as a sum of these two.

Most participants did not report log dreams on all days following the laboratory visit. Thus, to increase the number of valid observations available for repeated measures analyses of variance, incorporation scores for adjacent days were averaged (1 and 2, 3 and 4, etc.). Because participants underwent the VR maze task on the morning after sleeping in the laboratory, the 1st available day for post-maze incorporations was the 2nd day of the post-laboratory log; this resulted in 9 rather than 10 observations for post-maze analyses.

Figure 1. Top panel: map of the VR maze showing 3 interior environments connected by corridors; bottom 4 panels (clock wise from upper left): examples of environments including concrete interior, snow-filled outdoors, industrial interior, lava-filled river.

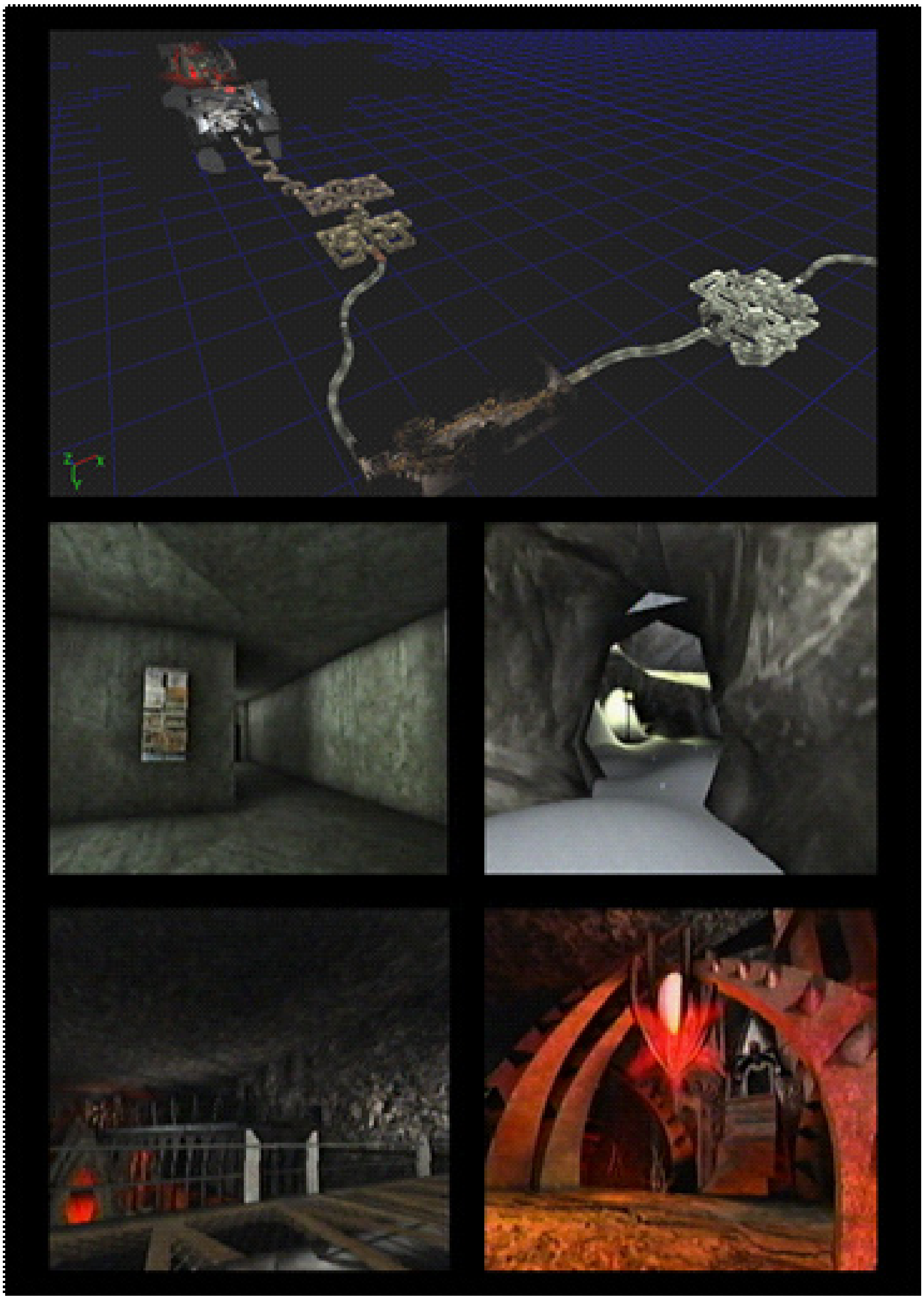
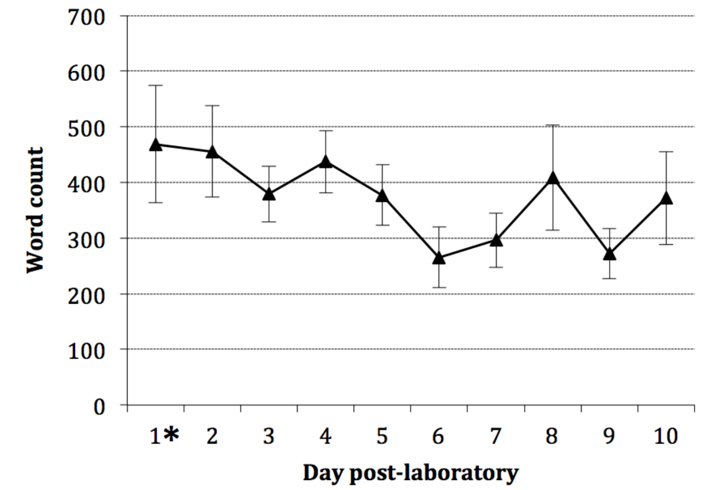


Figure 2. *Distribution of mean (±SEM) word counts for full dream reports across the 10 days of the dream log. *Day 1 dreams were reported and typed in the laboratory*



2.7. Statistical analyses

Curvilinear incorporation trends (linear, quadratic, cubic) were assessed with one-way ANOVAs with combined days (days 1+2, 3+4, 5+6, 7+8 and 9+10) as repeated measures. Differences in incorporation for peak and nadir days were assessed with independent samples t-tests. Differences in Dream LoC on peak and nadir incorporation days were assessed by independent samples t-tests. All analyses were performed using IBM SPSS Statistics 17 for Mac and PC.

3. Results

3.1. No effect of training on incorporation scores

Independent samples t-tests comparing TRN and CTL groups on LAB and VR maze incorporation scores as well as Dream LoC scores for both 'last 60 seconds' and 'rest of dream' reports produced no significant differences. Therefore, for all analyses of incorporation and Dream LoC the two groups were combined and the full dream reports were used.

3.2. Dream recall and task incorporations

Average post-laboratory dream recall was 6.9 out of 10 days (SD=2.46, range=1-10). A total of 180 dreams were collected, of which 178 (98.9%) contained 'last 60 seconds' reports and 127 (70.6%) contained 'rest of dream' reports. 125 (69.4%) contained both types of report; 53 (29.4%) consisted solely of 'last 60 seconds' reports; and 2 (1.1%) contained only 'rest of dream' reports. Dreams collected prior to the laboratory visit were assessed separately to determine the effects of training on dream recall and were excluded from current analyses.

The average number of dreams bearing any LAB incorporations was 1 per participant (SD=0.9, range=0-3); the average percentage of dreams with LAB incorporations per participant was 16% (SD=21%, range=0%-100%). The average number of dreams with VR maze incorporations was 0.9 (SD=3.0, range=0-3) while the average percentage was 12% (SD=12%; range=0%-38%). Six participants (23.1%) did not incorporate either the LAB or the VR maze, 4 (15.4%) incorporated the LAB but not the VR maze, and 1 (3.9%) incorporated the VR maze but not the LAB.

3.3. Dream recall and Total Word Count

Average word count for the 'last 60 seconds' part of the dreams was 201.6 (SD=166.7, range=3-890); and for the 'rest of dream' part was 236.1 (SD=187.6, range=4-827). Average full dream TWC for both parts combined was 365.9 words (SD=288.6, range=3-1506). Average TWC across the 10 days of the dream log are shown in Figure 2.

Independent samples t-tests performed on days with the most and the fewest words (days 1 and 6) revealed a marginally higher TWC score for day 1 (M=468.7, SD=406.9; n=15) than for day 6 (M=265.0, SD=225.2; n=17); t(21)=1.72, p=0.10.

Mean TWC did not differ for dreams bearing only LAB (M=376.0, SD=259, n=24) or only VR maze (M=417.3; SD=214.12; n=24) incorporations; t(44)=0.59, p=0.56. This comparison excluded the 2 dreams (1.1%) that contained both LAB and VR maze references. In 1 case, an indirect VR maze incorporation was scored for the 'last 60 seconds', with an indirect LAB incorporation for the 'rest of dream'. In the other case, both an indirect LAB and a direct VR incorporation were scored for the 'rest of dream'.

Some representative excerpts of dream reports scored as containing direct or indirect incorporations of LAB and VR maze experiences are presented in Table 1.

3.4. Immediate and delayed incorporation effects

Spearman non-parametric correlations revealed strong positive relationships between incorporation scores and #elements for both LAB and VR maze target elements, and strong negative relationships between LAB incorporation scores and #elements for VR maze variables (see Table 2). Based on the high degree of redundancy between the incorporation and #elements measures, we opted to use only the #elements measure for further analyses of incorporation patterns.

Table 1. Excerpts from log dreams containing laboratory (LAB) and virtual reality (VR) maze in-corporations with corresponding incorporation elements and Dream LoC scores (7-point scale: 1=internal, 4=both internal and external, 7=external).

Participant	Dream excerpt	Day and Type	Elements incorporated	LoC score
Male, 34 years old, TRN group	"… I feel as if I am inside a computer game. It is a maze… I turn left, then right, and then continue forward after more turns" (translated from French)	Day 3 VR maze	Direct: computer game, maze, navigating a sequence of environments	3
Male, 23 years old, TRN group	"… walking through my old high school … up and down various floors. (…) the hallways are all apparently empty, which is strange…"	Day 2 VR maze	Indirect: sequence of empty hallways	4
Female, 23 years old, TRN group	"… I wake up and get out of the laboratory bedroom. Laboratory is exactly the same as I saw it yesterday when I went to sleep. I see my friends L. and A. there (…) somebody is taking the electrodes off my head"	Day 1 LAB	Direct: laboratory, electrodes, experimenters	7
Male, 34 years old, CTL group	"I am being admitted to a hospital because I am unable to remember my dreams. A team of doctors stands over the gurney telling me that I must be hospitalized for eight days…"	Day 9 LAB	Indirect: hospital, dream recall training, experimenters	7
Male, 23 years old, TRN group	"… A man and his son are discussing some action to take, perhaps how to roll over with all these wires attached. But they are not in bed, the son is on the father's shoulders, (…), when they decide on what to do, they march towards the point of my perspective, though I feel omnipresent, like when an actor exits the scene by walking toward the camera…"	Day 1 LAB	Indirect: wires, bed	7
Male, 22 years old, control group	"Seascape. Night. Awareness of stars, but they were not clear. (…) Quite cartoonish. There were some 'sharks'… something arrived… the sharks began their defensive movements. The attacking thing retreated (…). They sat there, evenly spaced in front of me, (…) talking.	Day 1 LAB	Indirect: elements from training film clip presented in the lab	7

3.5. LAB Incorporations

The #LAB elements incorporated in dreams over the 10 post-laboratory days are plotted in Figure 3a. Most elements were observed for day 1 (M=0.87, SD=1.13), day 2 (M=0.24, SD=0.44), and day 9 (M=0.53. SD=1.12).

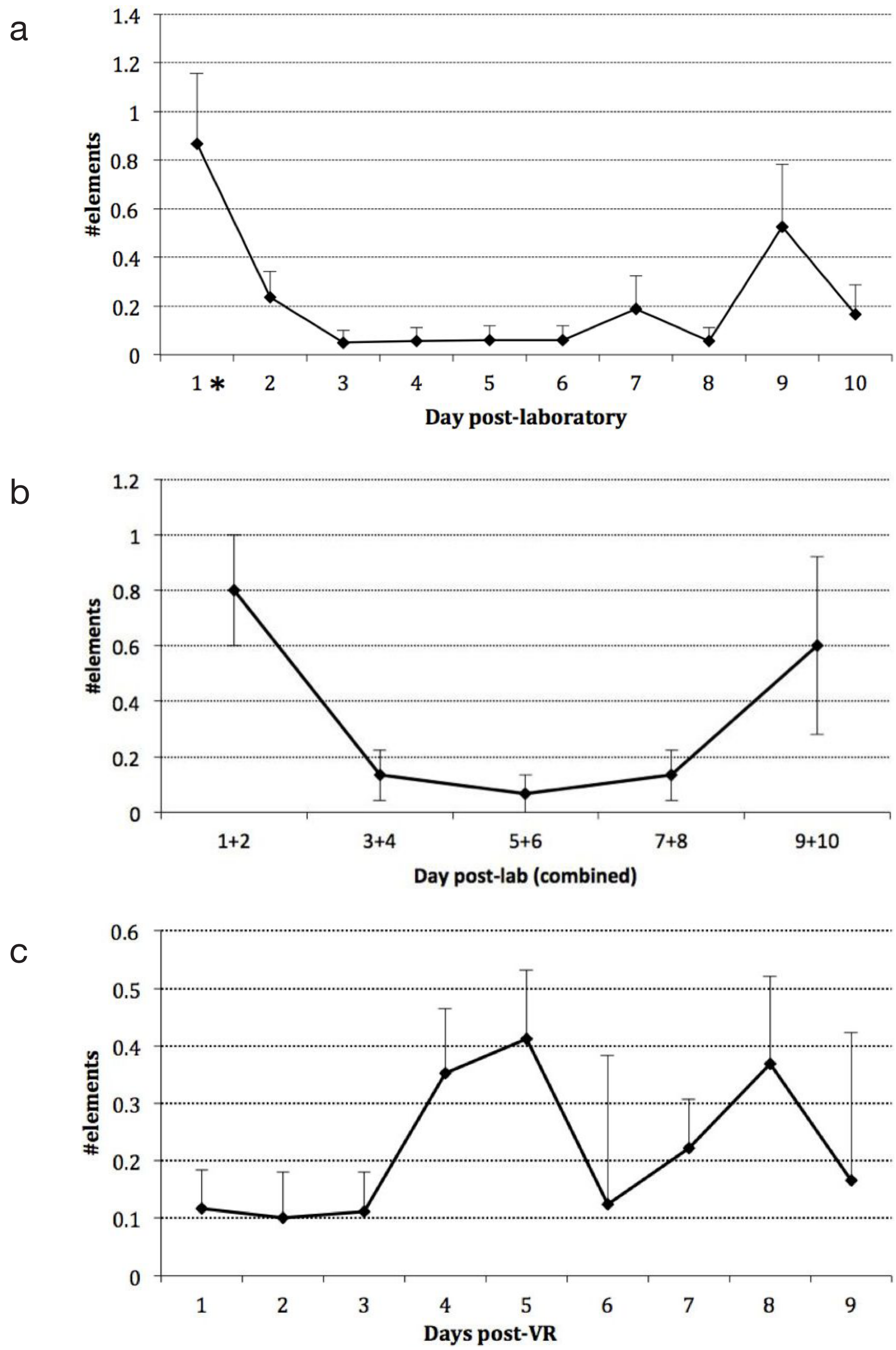
An ANOVA on #LAB elements with pairs of days (1+2, 3+4, 5+6, 7+8, 9+10) as repeated measures revealed a quadratic trend (F(1)=9.95, p=.007, N=15) describing a strong day-residue effect on days 1+2 (M=.80, SD=.76), followed by few elements on days 3+4 (M=.13, SD=.35), 5+6 (M=.07, SD=.26), and 7+8 (M=.13, SD=.35) and then a delayed dream-lag effect on days 9+10 (M=.60, SD=1.24). These scores are plotted in Figure 3b.

Table 2. Spearman correlations between incorporation scores and number of target elements (#elements) for laboratory (LAB) and VR maze (VR) scores. Large negative correlations between LAB and VR scores reflects the near total absence of dreams in which both types of stimuli were incorporated.

	LAB incorporation score	#LAB elements	VR incorporation score	#VR elements
LAB incorporation		.923*	-.890*	-.900*
#LAB elements	.923*		-.905*	-.915*
VR incorporation	-.890*	-.905*		.954*
#VR elements	.954*	-.915*	.954*	

Note. N=46; *p<.001

Figure 3. **a**: *Mean (±SEM) #LAB elements incorporated into dreams over the 10 days of the home log. *Day 1 dreams were reported and typed in the laboratory.* **b**: *Mean (±SEM) #LAB elements incorporated into dreams by pairs of post-laboratory days. Day-residue (Days 1+2) and delayed dream-lag (Days 9+10) effects are visible.* **c**: *Mean (±SEM) VR maze #elements over the 9 post-laboratory dream log days. Although more elements were identified for Day 5, more dreams with incorporated elements were identified for Day 4. *Day 1 dreams were typed at home and not in the laboratory, since the VR experience took place in the morning following the night in the laboratory.*



3.6. VR maze incorporations

The #VR maze elements incorporated over the 9 post-VR days is plotted in Figure 3c. Most elements were observed for day 4 (M=0.35, SD=0.49), day 5 (M=0.41, SD=1.06), and day 8 (M=0.37, SD=1.12).

An ANOVA for #VR maze incorporations with days (1+2, 3+4, 5+6, 7-9) as repeated measure did not reveal any statistically significant linear, quadratic or cubic trends. Although the greatest average #elements (0.41) was observed on day 5, the number of dreams bearing any VR incorporations for this day was only 3, whereas on day 4 the average #elements was slightly less (0.35) but the number of dreams with incorporations was 6. This is due to the #elements score on day 4 being inflated by a single dream containing 4 discrete VR elements. Therefore, for the following analyses we considered day 4 as having the most incorporations and compared it to days 2 and 6, which had comparably low incorporation scores (0.10 and 0.13). Independent samples t-tests revealed marginally higher #elements on post-VR maze day 4 (M=.35, SD=.49; N=17) than on day 2 (M=.1, SD=.31; N=20); t(35)=-1.84; p=.08; and than on day 6 (M=.13, SD=.34; N=16); t(29)=1.55, p=.13.

3.7. Locus of control

For the following analyses, the 6 participants who reported no incorporations of any kind over the course of the log were considered ‘non-incorporators’ and excluded from analyses of Dream LoC.

3.8. Dream LoC and incorporation pattern for #LAB elements

As shown in Figure 4a, independent samples t-tests comparing Dream LoC scores for days 1 and 5, i.e., the post-LAB days with the most and fewest #LAB elements incorporated respectively, revealed scores on day 1 that were significantly more external in nature (M=6.04, SD=1.28; N=13) than on day 5 (M=4.68, SD=1.65; N=14); t(25)=2.38, p=.025. A posthoc test revealed that this pattern was observed for the ‘last 60 seconds’ of the dream (day1: M=6.08, SD=1.56, N=13; day 5: M=4.57, SD=1.65, N=14); t(25)=2.44, p=.022, but not for the ‘rest of dream’; t(14)=.464, p=.65.

Similar t-tests performed on Dream LoC scores for days 5 and 9 did not reveal differences for full dream, ‘last 60 seconds’ or ‘rest of dream’ (see Figure 4a).

To test whether the observed Dream LoC differences were independent from the incorporation differences reported above, t-tests were repeated for the same days but with only those dreams that contained no incorporations. A partial independence of the two effects was suggested by the fact that Dream LoC scores on days 1 and 5 still produced a weak trend for more external Dream LoC on day 1 (M=5.64, SD=1.55, N=7) than on day 5 (M=4.53, SD=1.65, N=16) for the full dream; t(21)=1.51, p=.15; as well as for the ‘last 60 seconds’ (day1: M=5.57, SD=1.90, N=7; day5: M=4.38, SD=1.67, N=17); t(21)=1.52, p=.14; but not for the ‘rest of dream’; t(14)=1.00, p=.33.

3.9. Dream LoC and incorporation pattern for VR maze #elements

As shown in Figure 4b, independent samples t-tests comparing post-VR maze days 2 and 4, i.e., days with the most and least VR incorporations respectively, revealed a pattern opposite to that for #LAB elements. For the full dream, there was no significant difference in Dream LoC for days 2 (M=5.28, SD=1.67, N=16) and 4 (M=4.68, SD=1.65, N=14); t(28)=0.991, p=0.60. However, for the ‘last 60 seconds’ Dream LoC was more external on day 2 (M=5.69, SD=1.4, N=16) than on day 4 (M=4.57, SD=1.4, N=14); t(28)=2.00, p=.055. For the ‘rest of dream’, no difference was seen (day2: M=4.64, SD=2.37, N=14; day 4: M=5.22, SD=1.48, N=9); t(21)=-0.652, p=0.48. Similar analyses performed for days 4 and 6 did not reveal any differences for Dream LoC scores.

When considering only those dreams without any scored VR incorporations, a repeat of the previous t-tests revealed that the observed difference for the ‘last 60 seconds’ Dream LoC scores on days 2 and 4 was diminished (day2: M=5.71, SD=1.40, N=17; day4: M=4.73 SD=1.79, N=11); t(26)=1.62, p=.12).

3.10. Dream LoC before and after laboratory visit.

To test whether there were differences between Dream LoC scores prior to and after the laboratory visit, we calculated baseline Dream LoC scores by averaging scores for the 4 days before the LAB visit for the full dream, ‘last 60 seconds’ and ‘rest of dream’ measures. We then compared the baseline Dream LoC scores with those on peak and nadir days of LAB incorporation (days 1, 5 and 9 post-laboratory). These results are plotted in Figure 4c.

Independent samples t-tests revealed that, for the full dream Dream LoC measure, post LAB day 1 dreams were significantly more external (M=6.10, SD=1.21, N=15) than were baseline dreams (M=5.13, SD=.69, N=26, t(19)=-2.84, p=.010). This effect was true (t(39)=-2.60, p=.013) for the ‘last 60 seconds’ part (day 1 M=6.13, SD=1.46, N=15; baseline: M=5.12, SD=1.03, N=26) but only marginal (t(31)=-1.78, p=.086) for the ‘rest of dream’ part (day 1: M=5.78, SD=1.40, N=9; baseline: M=5.02, SD=.96, N=24) of the dream.

Post-LAB day 5 dreams (nadir of LAB incorporations and peak of VR incorporations) did not differ from baseline dreams on any of the 3 Dream LoC measures (all p>.10).

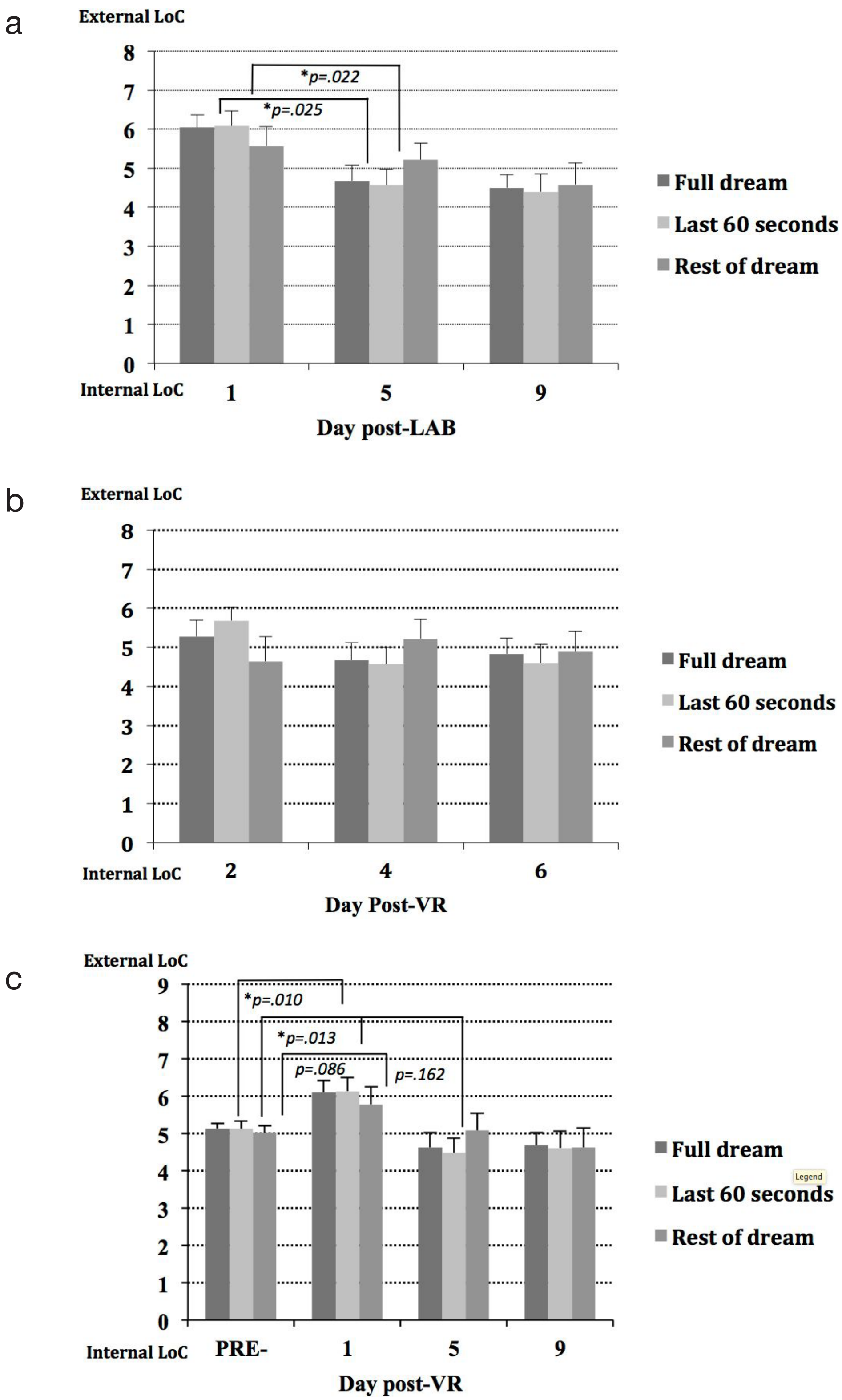
Post-LAB day 9 dreams (second peak of LAB incorporations) also did not differ from baseline for any of the 3 Dream LoC measures (all p>.05).

4. Discussion

4.1. Different target experiences lead to distinct dream formation processes.

The findings provide some support for the two hypotheses of the study. First, they support hypothesis 1 that the LAB and VR maze tasks would lead to different temporal patterns of dream content incorporation. LAB and VR maze elements were observed to be restricted almost entirely to different dreams; they appeared in the same dream on only 2 occasions and for one of these two indirect incorporations occurred in two different parts of the dream. Accordingly, there were strong negative correlations between scores for incorporation of LAB and VR maze elements. Further, incorporations of LAB elements showed a somewhat modified version of the expected U-shape curve, expressing both a day-residue effect on day 1 and a dream-lag effect on a later than expected day (Day 9 in this case), whereas incorporations of VR maze elements showed a markedly different

Figure 4. **a**: *Mean (±SEM) Dream LoC scores for post-LAB days with the most (Days 1 and 9) and least (Day 5) dreams with incorporated LAB elements.* **b**: *Mean (±SEM) Dream LoC scores for post-VR maze days with the least (Days 2 and 6) and most (Day 4) dreams with incorporated VR maze elements.* **c**: *Mean (±SEM) Dream LoC scores for pre-laboratory baseline dreams (PRE-) and post-LAB dreams from days 1 (most LAB incorporations), 5 (least LAB and most VR incorporations), and 9 (second peak of LAB incorporations).*



pattern: a peak on days 4 and 5 that was preceded and followed by days with relatively few incorporations.

Second, the results support hypothesis 2 that Dream LoC will differ for dreams with different types of target stimulus incorporation. In this case, there was evidence that the dreams highest in LAB elements reflected a LoC that was more external in nature, whereas dreams highest in VR maze elements reflected a LoC that was relatively more internal; on average it fell on the midpoint of the scale, reflecting a combination of both internal and external LoC.

Together, these results support the notion that two distinct, albeit concurrent, target experiences stimulated dream formation processes that were temporally distinct and characterized by changes that were both specific (incorporated elements) and general (Dream LoC) in nature.

4.2. Different day-residue effects

The day-residue effect for LAB incorporations was most pronounced for dreams that were collected after participants were awakened from their morning REM sleep periods in the laboratory (8 dreams, 53% of all 15 dreams collected at that time). This strong effect is consistent with a wealth of previous research reviewed in the Introduction although is somewhat higher than the values typically reported from early studies, e.g., 33% (Dement et al., 1965) or 35% (Jouvet, 1999). Rather, our effect is more in line with those of more recent studies (Fosse et al., 2003) showing that 51% of dream reports from a home log contain at least one reference to any type of recent experience at all. Although the reasons for our higher level of day-residue incorporations remain unclear (e.g., our LAB experience may have been exceptionally impactful), the stark contrast of this level with that for our VR maze task (2 dreams of 17 collected, 11% of dreams) suggests that the LAB stimulus alone triggered a day-residue effect in this study. One possible explanation may be that the LAB day-residue took place in the laboratory, thus being a contemporaneous context incorporation in addition to the incorporation of pre-sleep experiences in the laboratory. This fact may increase the likelihood of LAB-related elements appearing in the dream report.

This selective day-residue effect for LAB incorporations raises the possibility that the close temporal proximity of the LAB and VR experiences led to a competition for their expression as day-residues in later dream content. This notion of competition is similar to the observation that declarative and motor skill tasks that are learned in quick succession interfere with one another (Cohen & Robertson, 2011). In fact, in a previous study in our laboratory (Saucier, 2007), participants who underwent the same VR maze task, but without the potentially interfering effect of the laboratory stay-over, did show robust day-residue incorporations of the VR maze. The lack of an overnight stay in that study may have removed a second personally significant experience that ultimately interfered with the offline processing of the VR maze experience in the present study—including its reactivation during dreaming.

Dream-related interference between competing experiences may also be influenced by which of the experiences is encountered first. In the present case, the laboratory sleepover began about 12 h before the VR maze task, and was free to appear without interference in dream content as a day-residue because the VR maze task had not yet been encountered. Further, once the VR task had been completed, LAB-related memory processes may have continued to exert an inhibitory influence on its expression the following night. If this was the case then our results suggest that processing of the VR maze task may not have been released from this inhibitory influence until fully 5 days later (post-VR day 4; post-LAB day 5) when the first clear VR maze incorporations occurred.

It is thus possible that the memory processes underlying treatment of the selected day-residue ‘reserve’ an invariant inhibitory window of 3-4 days to complete their consolidation function, such that treatment of other memories is postponed until that function is complete. This might explain why, in previous home log studies, the lowest levels of dream incorporation are consistently seen to be on days 3-4 following a target event. In contrast, when target stimuli are combined with laboratory sleep, an inverse pattern is sometimes seen. In one study (Nielsen & Powell, 1995) participants exposed to a stressful film before sleeping overnight in the laboratory reported dreams containing elements of the film only 4 days following the stimulus. Since participants also slept in the sleep laboratory, the results are a striking parallel to those of the present study.

Another possible factor that may have influenced the differential timing of the day-residue effect in the 2 experiences is that they were differentially salient and self-relevant. The sleep laboratory experience may have had more of an emotional, interpersonal impact, and may therefore have been given a preferential—and enduring—treatment by memory processes. This notion is consistent both with previous findings showing that the day-residue and dream-lag effects are linked to personally relevant experiences (Nielsen et al., 2004) and with current theories and evidence suggesting that there is a self-relevance selection bias in memory consolidation (Labar & Cabeza, 2006; Hamann, 2001). Also consistent with this are the results of a single participant study (Kookoolis et al., 2010) in which personally significant events were found to be incorporated earlier, on days 1 and 2, than were objects, which appeared on days 3 and 4. That our subjects underwent dream report training sessions in the laboratory, which included multiple awakenings for dream collection, may have substantially enhanced the salience and perceived personal importance of the laboratory experience for them.

Additionally, it is possible that a major component of the laboratory experience that leads to its robust expression as a day-residue effect is the interpersonal dimension in which the participant is placed in a more passive role than usual. We expected to see—and found—this dynamic reflected in changes in the Dream LoC measure (see later section).

Finally, the variability of incorporation patterns of day-residue and dream-lag effects, such as those described in the current study, could represent random fluctuations in stimulus incorporation patterns. It might be argued that, given the number of new memories that are formed each day, it is implausible that the dream-lag would occur for one memory at a time, but we contend that to the extent that dreams process memories of important life events, of which there are arguably very few in a day, it is conceivable that these memories are processed in the dream in a more sequential fashion, i.e. one at a time.

In sum, the occurrence of a very robust day-residue effect for the LAB stimulus in the present study replicates a great deal of prior research whereas the observation of a possible 4-day delay in the day-residue effect for the VR maze stimulus also parallels the results of some other studies in which target stimuli were combined with sleeping in the laboratory. That day-residue incorporations of VR stimuli appear to be delayed remains unexplained, but may be a function of the event's timing, the integrity of intervening REM sleep, the stimulus' effects on physiological systems, its relevance to participants, or the interpersonal context in which the participant is placed. We suggest that the apparent delay occurred because the offline processing of the VR experience was in competition with the processing of the LAB experience, and that this reflects inhibitory mechanisms that function during a fixed window of 3-4 days. This possibility of a 3- to 4-day 'exclusion period' for competing stimuli might be clarified in future studies by presenting self-relevant and irrelevant source stimuli at a wider range of different times prior to dream sampling.

4.3. Partial replication of the dream-lag effect

The two types of stimulus event used in this study both produced unexpectedly delayed dream-lag effects. The dream-lag effect for LAB elements was observed 9 days post-stimulus whereas that for the VR maze was observed 8 days post-stimulus. Both of these delays are longer than is usually seen in other studies (5-7 days) (Nielsen & Powell, 1989; Blagrove & Pace-Schott, 2010; Blagrove et al., 2011a; Blagrove et al., 2011b; van Rijn et al., 2015). Nonetheless, delays of this magnitude have been reported. Jouvet's (1979) analysis of samples of his personal dreams revealed that when he travelled to a new destination for any length of time, incorporations of elements of the new environment did not peak in his dreams until 8 days after departure, whereas when he returned home from long trips, elements of his home environment did not reappear in his dreams until 8-10 days later. Other studies have observed delayed incorporations occurring 10 days after a stressful film (Powell et al., 1995) or 12 days after an emotionally negative daytime event (Nielsen & Powell, 1992) but, unlike the present study, the latter two effects were coupled either with a delayed day-residue effect (day 4) or normal day-residue (day 1) and dream-lag (day 6) effects respectively. One possible explanation for the delayed dream-lag effect for LAB elements is the same as the one previously suggested to explain the delayed (4-day) processing of the VR maze stimulus. Once the VR maze stimulus was successfully incorporated in dream content on day 4 (day 5 relative to the LAB experience) it, in turn, may have excluded the reoccurrence of LAB elements in dream content for another 4 days. Consequently, the reappearance of the LAB stimulus may have been delayed from the usual 5-7 days to the 9-10 days observed.

Another possible explanation for the delayed dream-lag effects for both LAB and VR maze stimuli is that around days 8 or 9 participants were reminded that the end of the study was imminent, that they would be required to meet the experimenter again, receive their financial compensation, etc. The emotional salience of this reminder may have been sufficient to trigger a new round of incorporations of the LAB and VR maze stimuli around this time—a type of secondary day-residue effect. Such an 'end of study' explanation suggests that memory sources of dreams may be reactivated by salient reminders, an effect that has not yet been demonstrated in the literature. Nonetheless, it is an easily testable hypothesis, which could clarify an important source of variability observed in studies of the dream-lag effect.

4.4. Relationship between dream LoC and incorporation patterns

The second hypothesis of this study, that Dream LoC will be more external for dreams high in LAB incorporations and more internal for dreams high in VR maze incorporations, was partially confirmed. For dreams that were high in LAB incorporations, average Dream LoC was, in fact, more external whereas for dreams high in VR maze incorporations, it was relatively less external and more internal. Moreover, when comparing Dream LoC scores for peak incorporation days with pre-laboratory averages (baseline), dreams that were high in LAB incorporations (day 1) had relatively more external LoC scores. This was not the case for dreams from day 9 however. Also, no change in Dream LoC was seen for dreams high in VR maze incorporations relative to baseline.

It might be argued that the observed changes in Dream LoC are due simply to a confounding of the incorporation and LoC measures, i.e., that Dream LoC scores were simply reiterating the relative external or internal nature of the incorporated stimulus elements. Analyses confirmed this consideration to some extent in that observed Dream LoC differences between dreams occurring on peak and nadir incorporation days were reduced to statistical trends when prior differences in LAB and VR maze incorporations (#elements) were controlled. However, the fact that trends still remained suggests that Dream LoC scores are at least partially independent of incorporation scores. They may, therefore, reflect more general changes in dream content that are brought about by exposure to the target stimuli. In the case of dreams that are influenced by the LAB experience, for example, this may mean that processing of the interpersonal relationships inherent to being a laboratory participant (presumably a more external LoC situation) occurs to some extent on a global level that affects the dream narrative as a whole.

Both the dependence and the independence of the incorporation and Dream LoC measures can be illustrated with examples from our dream sample presented in Table 1. Dependence between the measures is quite obvious in instances in which the Dream LoC score (external vs. internal) parallels the incorporation score (LAB vs. VR maze), with higher external scores for dreams with LAB incorporations and higher internal scores for dreams with VR elements. For example, in the two first dreams with VR incorporations (see examples 1 and 2), both scored as relatively internal in LoC, participants referred to being "…inside a computer game, it is a maze. I turn left, then right, then right…", and to "… walking up and down various floors". Similarly, in some examples of LAB incorporations, scored as external LoC, one participant reported being "…in the laboratory bedroom" while "… somebody is taking electrodes off my head", and another one dreamt of being "admitted to a hospital" where "a team of doctors stands over the gurney, telling me that I must be hospitalized."

On the other hand, independence between incorporation and LoC measures is suggested by cases in which a LAB incorporation in a dream that was scored high on external Dream LoC cannot be easily accounted for by reactivation of the LAB situation. For example,: "…A man and his son are discussing some action to take, perhaps how to roll over with all these wires attached (…) When they decide what to do, they march toward the point of my perspective, I feel omnipresent…". In this dream, that occurred on day1 (peak of LAB incorporations), the high external Dream LoC score cannot obviously be attributed to a confounding of LAB elements (wires, bed) with LoC. Rather, these elements played only an enabling role in the other characters' intentions to act. In other words, the external LoC score stemmed from the characters' actions and not from the mere presence of the LAB elements in the dream. Similarly, consider this dream part: "…Seascape. Night. Awareness of stars, but they were not clear. (…) Quite cartoonish. I don't remember whether I was on a boat or somehow a floating observer. There were some 'sharks'… something arrived… the sharks began their defensive movements. The attacking thing retreated. (…) They sat there, evenly spaced in front of me, (…) talking." Here, the cartoonish quality, and the nighttime and presence of stars were scored as indirect LAB incorporations because of their close resemblance to elements of the short animated film clip that the participant saw in the lab during the dream reporting training session. But the high external Dream LoC here, again, was scored because the dreamer was an observer to external events and not simply because laboratory elements were present in the dream.

This partial independence between incorporation and LoC measures is consistent with our suggestion that dreams often respond to target stimuli in a variety of ways, including by depicting specific memory elements (direct incorporations), quasi-disguised or transformed memory elements (indirect incorporations), and global changes in the entire dream narrative (Dream LoC). Although the present Dream LoC results require replication, they nonetheless support our view that dreaming reacts to significant daytime events with general as well as specific changes. This exploratory part of the study revealed that stimulus-driven generic changes in dream content can be assessed with a LoC scale adapted specifically for application to dream content. Identification of additional general changes in dream content would be a valuable advance in the emerging neuroscientific study of dreaming and memory. At present, investigators have relied primarily upon direct or indirect incorporations of tasks as evidence that dream content is reacting to these tasks. To illustrate, Wamsley and Stickgold (2011) point out that in dream content elements of recent learning experiences are intermixed with remote memories, semantic information and other types of cognitions to produce sometimes bizarre scenarios and that this is due to 'long-term potentiation–like plasticity in mnemonic networks' and processes responsible for the 'extraction of meaning' (p. 104). In other words, dream incorporations reflect underlying memory processes of both encoding and integrating of new experiences with previous knowledge. The day-residue and dream-lag effects observed in the present study may partially represent these processes at an experiential level. These offline mechanisms are thought by many to be hippocampally-mediated, and one of their functions to be 'integrative encoding'; a mechanism that enables a synthesis and a generalization of distinct yet related experiences (Shohamy & Wagner, 2008).

Our results could be taken to suggest that these as yet unobserved processes behind dreaming may be detectible in general changes in dream content such as a shift toward a more external locus of control in the basic structure of the dream. LoC is but one of many such general features. For example, DeKoninck and colleagues (De Koninck, Prevost, & Lortie-Lussier, 1996) found that dreams reported in response to the wearing of inverting lenses included direct incorporations (e.g., upside down objects) but also general changes (e.g., misfortunes, confusion). Similarly, Smith and Hanke (2004) found that dreams following a mirror-tracing task contained more driving mistakes and mishaps.

Taken together, findings for the two hypotheses of the study are consistent with the suggestion that dreams tend to deal with one impactful daytime event at a time—possibly even actively excluding other events from being dealt with—and that this reaction includes activation of at least one generic mechanism that is sensitive to the balance of self/non-self agency in the dream narrative.

4.5. Limitations of the study

The most obvious limitation of the current study is its sample size. The fact that missing observations are very common for protocols requiring dream recall over multiple days (average dream recall for the general population is 2-3 dreams/week; Kramer, Winget, & Whitman, 1971) impeded our use of repeated measures designs. This was dealt with to some extent for the calculation of polynomial trends by combining results for adjacent days, but for other comparisons we were obliged to use multiple independent sample t-tests. A second limitation is the length of the dream log for assessment of VR maze elements (9-10 days). Because we observed a peak incorporation for this measure on day 4, we could not evaluate whether a delayed dream-lag effect occurred after about a week (day 11) or perhaps even later as might be expected, or whether it simply did not occur at all. Longer dream logs in future studies would avoid this problem. A third limitation is that some differences were observed only for parts of the dream report. For example, a Dream LoC difference between days low (day 2; external LoC) and high (day 4; internal LoC) in VR maze incorporations was only found for the 'last 60 seconds' part of the dream. This finding may be artifactual in that 30% of collected dreams contained no 'rest of dream' report, thus reducing the N for statistical evaluation of the latter. But the finding is also consistent with the possibility that some LoC changes are quite ephemeral and that their accurate identification depends upon the use of a more structured dream collection procedure that focuses a participant's attention on the most recently recallable material. Finally, an important study limitation is that the dreams expressing the day-residue effect for LAB elements (day1 dreams) were reported in the laboratory rather than the home log. The presence of experimenters during dream collection may have influenced dream content in unknown ways, including producing more external LoC features, and may have increased laboratory incorporations (Schredl, 2008). However, there is evidence that dreams obtained in the laboratory and at home differ very little in content (Domhoff & Schneider, 1998). Also, in the present study the length of dream reports obtained in the laboratory did not differ significantly from that of dream reports obtained from the 10-day home log.

Acknowledgements

Sebastien Saucier for help with the Virtual Reality installation, Social Sciences and Humanities Research Council of Canada (SSHRC) grant to TN, Quebec's Health Research Funds (FRSQ) master's scholarship and a SSHRC doctoral scholarship to ES.

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