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Lucid dreaming and ventromedial versus dorsolateral prefrontal task performance

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ABSTRACT

Activity in the prefrontal cortex may distinguish the meta-awareness experienced during lucid dreams from its absence in normal dreams. To examine a possible relationship between dream lucidity and prefrontal task performance, we carried out a prospective study in 28 high school students. Participants performed the Wisconsin Card Sort and Iowa Gambling tasks, then for 1 week kept dream journals and reported sleep quality and lucidity-related dream characteristics. Participants who exhibited a greater degree of lucidity performed significantly better on the task that engages the ventromedial prefrontal cortex (the Iowa Gambling Task), but degree of lucidity achieved did not distinguish performance on the task that engages the dorsolateral prefrontal cortex (the Wisconsin Card Sort Task), nor did it distinguish self-reported sleep quality or baseline characteristics. The association between performance on the Iowa Gambling Task and lucidity suggests a connection between lucid dreaming and ventromedial prefrontal function.

1. Introduction

Dreaming is a state of consciousness that shares some characteristics with waking consciousness. In both states, there is an awareness of objects and events, and an awareness of oneself (Cicogna & Bosinelli, 2001). This similarity of awareness may reflect similar brain activation. In particular, forebrain activation by ascending arousal systems of the brainstem, diencephalon and basal forebrain promote consciousness in both waking and dreaming, albeit by anatomically and neurochemically distinct mechanisms (Hobson, 1988; Hobson, Pace-Schott, & Stickgold, 2000; Muzur, Pace-Schott, & Hobson, 2002). A key difference in the conscious experience of waking, however, is the presence of meta-awareness or self-consciousness – insight into ones mental state. For example, in waking but not in dreaming there is an awareness of being awake, and the ability conceive of and differentiate the waking state from alternate mental states such as dreaming (Pace-Schott, 2010; Rechtschaffen, 1978).

A notable exception to this generality, however, is the phenomenon of lucid dreaming – the explicit awareness, while dreaming, that one is dreaming (LaBerge, 1990, 1992, 2000, 2007). Lucidity may also be accompanied by the ability to exert deliberate control over dream outcome (LaBerge, 2007). Although the detection and characterization of lucid dreams must rely to a great extent on the report of the dreamer, pioneering experiments by LaBerge and colleagues demonstrated that experienced lucid dreamers were able to signal that they were having a lucid dream by specific eye movements,

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pre-determined before sleep and detected by electro-oculogram during REM sleep (Laberge, Nagel, Dement, & Zarcone, 1981) as well as by voluntary control of respiration (LaBerge, 1990).

Fully lucid dreams occur on a continuum of lucidity with typical dreams (Barrett, 1992; Lequerica, 1996). Training can increase the frequency of lucid dreams and the degree of lucidity achieved (LaBerge, 1990; Purcell, Mullington, Moffitt, Hoffmann, & Pigeau, 1986), with proficient lucid dreamers typically achieving their results only after extensive self-training (LaBerge, 1990, 1992, 2000, 2007). Despite the rarity of spontaneous lucidity, metacognition in dreams, or a degree of self-reflection about dream thoughts, intentions and feelings, may be more common than previously thought (Kahan & LaBerge, 1994; Kahan, Laberge, Levitan, & Zimbardo, 1997). For example, a study directly comparing waking and normal dreaming found similar levels of self-reflection and about half as much voluntary choice in dreams relative to waking (LaBerge, 2000). Similarly, the ability to reflect on the contents of ones own and other dream characters' minds, (so-called "theory-of-mind"; Frith & Frith, 2006), has been shown to be ubiquitous in dreaming (Kahn & Hobson, 2005; Macnamara, Mclaren, Wowalczyk, & Pace-Schott, 2007; Pace-Schott, 2001).

Both normal and lucid dreaming are most commonly reported following awakenings from REM-containing periods of sleep (Hobson et al., 2000; LaBerge, 1990, 1992, 2000, 2007; Nielsen, 2000). Whereas there is a substantial rate of reporting normal dreaming following awakenings from non-REM (NREM) sleep (Foulkes, 1962; Nielsen, 2000), lucid dreaming appears to be much more closely related to REM sleep (LaBerge, 1990, 1992, 2000, 2007). Brain activity during lucid dreams is similar to that during typical REM sleep in some respects (e.g. the absence of waking-like alpha [8–12 Hz] activity), but differs in others (e.g. brain activity over 30 Hz) (Voss, Holzmann, Tuin, & Hobson, 2009). Hence lucid dreams may arise from periods of REM sleep (e.g. with transient elevation of brain activity during the phasic [rapid eye movement containing] periods of REM (Brylowski, Levitan, & Laberge, 1989; LaBerge, 2007)), but are not REM sleep phenomena *per se* (Voss et al., 2009).

In typical dreams, the lack of awareness that one is dreaming has been attributed to deactivation of lateral frontal executive areas relative to waking (Hobson et al., 2000; Muzur et al., 2002). Indeed, it is these frontolateral regions, along with certain posterior multimodal association areas, that PET studies have shown remain deactivated throughout sleep, including REM (Braun et al., 1998; Braun, Balkin, Wesenten, et al., 1997; Maquet, Peters, Aerts, et al., 1996; Maquet, Ruby, Maudoux, et al., 2005). Such deactivation during normal dreaming may impair working memory such that the ability to retrospectively compare ongoing experience to experiences moments earlier is lost (Pace-Schott, 2005). If lack of lucidity in typical dreams reflects deactivation of frontal executive areas, it follows that lucid dreams may be characterized by relatively preserved or transiently elevated frontal activity with concomitant elevation of cognitive abilities that support executive function. Both fMRI and quantitative EEG studies have demonstrated elevation of cortical activity during phasic versus tonic REM (Abe, Ogawa, Nittono, & Hori, 2008; Corsi-Cabrera, Guevara, & Del Rio-Portilla, 2008; Miyauchi, Misaki, Kan, Fukunaga, & Koike, 2009; Wehrle, Kaufmann, Wetter, et al., 2007). Moreover a recent quantitative EEG study found similarly high gamma band (30–80 Hz) coherence in lateral frontal areas during waking and lucid dreaming that, in both of these states, was higher than in normal REM sleep (Voss et al., 2009). Therefore, as with polysomnographic studies, functional neuroimaging and quantitative EEG studies suggest that dream lucidity may be associated with transient elevation of frontal cortical activity.

Whereas the lateral frontal cortex typically remains deactivated relative to waking following the transition from NREM to REM, ventromedial prefrontal and anterior cingulate cortices reactivate as part of what has been termed the "anterior paralimbic REM activation area" (Nofzinger, Mintun, Wiseman, Kupfer, & Moore, 1997; Nofzinger et al., 2004). This region can become activated in REM to levels exceeding waking (Nofzinger et al., 1997, 2004) and includes much of the subcortical limbic system (amygdala, ventral striatum, hypothalamus, basal forebrain) as well as other paralimbic cortices (e.g. parahippocampal and insular cortices; Nofzinger et al., 1997, 2004; and for review see Pace-Schott, 2010). Therefore, in addition to elevated activity in lateral frontal areas during lucid dreaming, it is possible that *further* elevation of REM-related activity in these ventromedial prefrontal regions also occurs during lucid dreaming. In waking, these ventromedial prefrontal areas support not only the self-related, social and emotional cognition that is ubiquitous in dream phenomenology (reviewed in Pace-Schott, 2010), but also support the affective guidance hypothesized to facilitate decision making (i.e. the Somatic Marker Hypothesis; Bechara, Damasio, & Damasio, 2000; Damasio, 2003).

In the present study our objective was to determine whether frontal cognitive and emotional, executive functions differed in persons who more readily have lucid dreams and those who do not. Answering this question relies on the observation that some individuals are more likely to have lucid dreams than others, and that this difference is stable (i.e. lucidity tends to reoccur in those who experience it; LaBerge, 1990, 1992). Hence individuals can be distinguished by their trait ability to more easily achieve degrees of lucidity. This trait may be related to neuropsychological traits with a similar degree of stability such as performance on executive function tasks. We hypothesized that performance on cognitive tasks that engage prefrontal cortical areas would differ between lucid and non-lucid dreamers. In particular, we hypothesized that lucid dreamers would show better performance on a cognitive task that engaged a brain region relevant to lucid dreaming, and hence potentially implicated in meta-awareness or other characteristics of the conscious experience.

To test this hypothesis we examined performance on two frontal cognitive tasks, the Wisconsin Card Sort Task (WCST; Berg, 1948) and the Iowa Gambling Task (IGT; Bechara, Damasio, Damasio, & Anderson, 1994; Bechara, Damasio, Damasio, & Lee, 1999), in high school students. The WCST and the IGT were chosen because performance of the former activates the dorsolateral prefrontal cortex (DLPFC; Ko, Monchi, Ptito, Petrides, & Strafella, 2008; Monchi, Petrides, Petre, Worsley, & Dagher, 2001) and performance of the latter activates the ventromedial prefrontal cortex (VMPFC; Lawrence, Jollant, O'daly, Zelaya, & Phillips, 2009; Li, Lu, D'argembeau, Ng, & Bechara, 2010; Lin, Chiu, Cheng, & Hsieh, 2008). (Note however, that as event-related fMRI designs have become more temporally precise, more diverse frontal and striatal regions are seen to