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Mental time travel to the future might be reduced in sleep

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ABSTRACT

We present a quantitative study of mental time travel to the future in sleep. Three independent, blind judges analysed a total of 563 physiology-monitored mentation reports from sleep onset, REM sleep, non-REM sleep, and waking. The linguistic tool for the mentation report analysis is based on established grammatical and cognitive-semantic theories and has been validated in previous studies. Our data indicate that REM and non-REM sleep must be characterized by a reduction in mental time travel to the future, which would support earlier physiological evidence at the level of brain function.

1. Introduction

The current study seeks to quantify mental time travel to the future in sleep. Mental time travel to the future is investigated as the ability to project oneself into possible future scenarios (D'Argembeau & Mathy, 2011; Ingvar, 1985; Schacter, Addis, & Buckner, 2007). The study of human memory has shown that the human ability to become aware of personal experiences from times other than the present not only applies to episodic memories of the past, but also to one's personal imagined future, and that these similar cognitive capacities both tend to be affected in amnesia (Botzung, Denkova, & Manning, 2008; Cole, Staugaard, & Berntsen, 2016; Gardiner, 2001; Klein, Loftus, & Kihlstrom, 2002; Piolino et al., 2001; Suddendorf & Corballis, 2007; Tulving, 1985; Wheeler, Stuss, & Tulving, 1997). Mental time travel to the future, unlike remembering past episodes, depends on imaginative capacities, and it has been suggested that the driving factor behind differences in remembering the past and imagining the future may not (only) be the difference in temporal domain (past versus future), but a difference in the degree of imagination required to picture fictional events versus recalling episodic memories of events that we have actually experienced (Schacter et al., 2012). Interestingly, this difference in psychological processes involved in memory for the past and in future episodic thinking (mental time travel) appears to extend to neuronal processing. A number of studies (Abraham, von Cramon, & Schubotz, 2008; Botzung et al., 2008; Weiler, Suchan, & Daum, 2010) indicate that the hippocampus shows greater activity when remembering past episodes as opposed to imagining the future. However, previous studies on the role of the hippocampus in mental time travel have brought divergent results, as the right hippocampus has been reported to show greater activity when a person is thinking about future events in comparison to past events (Addis, Wong, & Schacter, 2007). Furthermore, activity patterns within the default mode network (DMN), and especially the

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medial temporal lobe, appear to differ depending on whether participants think about themselves in a present situation, or whether they project themselves into a future situation (Andrews-Hanna, 2012).

Mental time travel to the future is considered to bring evolutionary advantages for waking life, where plans to obtain and potentially store food or avoid predators, for example, might always have been critical for survival (Klein, Robertson, & Delton, 2011; Martin, Schacter, Corballis, & Addis, 2011; Quoidbach, Hansenne, & Mottet, 2008). Physiological evidence at the level of brain function suggests that REM sleep and non-REM sleep on the other hand may be characterized by memory inhibition: REM and non-REM sleep bring aminergic neurodemodulation, along with the deactivation of dorsolateral prefrontal cortical structures associated with cognitive processes such as memory and planning, and the inhibition of the hippocampal-neocortical transfer associated with recall of episodic past memories in waking (Buzsáki, 1996; Hobson, Stickgold, & Pace-Schott, 1998; Maquet, 2001; Muzur, Pace-Schott, & Hobson, 2002; Stickgold, Malia, Fosse, Propper, & Hobson, 2001). Recent studies further indicate that imagining the future depends on much of the same neuronal structures that are needed for remembering the past, especially prefrontal and hippocampal regions, but also the medial temporal lobes (Benoit & Schacter, 2015; Hassabis, Kumaran, Vann, & Maguire, 2006; Schacter et al., 2007; Stawarczyk & D'Argembeau, 2015).

Predictions about the inhibition of mental time travel to the future in both REM and non-REM sleep can be made on the basis of the AIM Model (Hobson, Pace-Schott, & Stickgold, 2000), which describes characteristics in the mentation associated with states of consciousness as functions of specific neurophysiological processes: The **A**(ctivation) axis of the AIM Model depicts the different levels of overall and regional brain activation during waking, REM sleep, and non-REM sleep. The **I** (nput-output gating) axis shows how levels of brain activation are externally or internally generated, depending on input-output gating mechanisms in the brain stem. The **M**(odulation) axis depicts accompanying shifts in cholinergic-aminergic neuromodulation (for details see Hobson et al., 2000). With regard to mental time travel to the future, the cholinergic-aminergic neuromodulation is of primary interest. During waking, pontine aminergic neurons are tonically active and inhibit pontine cholinergic neurons. Aminergic activity decreases gradually in non-REM sleep, and vanishes in REM sleep. Aminergic inactivity is accompanied by the activation of pontine cholinergic neurons and, amongst other processes, selective deactivation of prefrontal regions, namely the dorsolateral prefrontal cortex and the orbitofrontal cortex (Maquet et al., 1996, 1997). Fosse, Stickgold, and Hobson (2001) correspondingly report evidence from mentation reports indicating a steady decline in cognitive functions most likely associated with aminergic-cholinergic modulation occurring during sleepers' transition from waking to non-REM and REM sleep. Importantly, previous studies suggest that the dorsolateral prefrontal cortex and the orbitofrontal cortex play a vital role for mental time travel to the future (Flinn, Geary, & Ward, 2005; Schacter et al., 2007; Suddendorf & Corballis, 2007).

Considering the evidence showing an overlap in neural structures underlying memory for the past and mental time travel to the future, it is important to note that phenomenological evidence matches neurophysiological evidence for impaired memory of the past in REM and non-REM sleep. First studies on memory in spontaneous brain activity have been carried out employing so-called no-task, no-stimulus, no-response paradigms (see Vaitl et al., 2005). In this type of paradigm, participants are subject to a situation where no specific stimuli are administered, and they are not asked to fulfil a specific task or give a specific response, other than provide a free report on their mentation after the mentation experience itself. Baylor and Cavallero (2001) collected such reports on their participants' mentation, and afterwards played them back to their participants, asking them to identify the memory sources. They observed that fewer episodic memory sources, as classified by the participants, derived from REM than from non-REM dream reports. Fosse, Fosse, Hobson, and Stickgold (2003) found that episodic past memories had not been replayed in both REM and non-REM dreams when asking participants to match their own dream experiences to their daytime activities over a 14-day period. Interestingly, when later rated by five external judges, less than two percent of the matched dream elements met the definition of episodic memories.

The findings outlined above may at times appear to stand in opposition to a large body of research suggesting that sleep serves memory consolidation. As noted by Stickgold, Hobson, Fosse, and Fosse (2001), one might expect that the physiological process of memory consolidation will express itself in the (dream) mentation, and a number of studies support the assumption that sleep does indeed play a role in replay and consolidation of declarative memories (and thus also episodic memories; see Rasch & Born, 2013, for a review). There is further evidence of hippocampal-cortical transfer of episodic memory in non-REM sleep, where episodic memory traces in the hippocampus are transferred to cortical centres during a state of low cholinergic tone. This transfer is thought to break down during the highly cholinergic REM state (Diekelmann & Born, 2010; Mander et al., 2013; Power, 2004; Takashima et al., 2006). This physiological model would predict that non-REM, but not REM sleep, permits past episodic memory recall, as reactivation of the hippocampal-cortical transfer allows for the consolidation of declarative memory. However, after linking physiological and behavioural evidence that support a strong association between sleep and memory consolidation, Rasch and Born (2013, p. 699) state that, with regard to dreaming, there is "so far no convincing evidence for a direct link between the reactivation of newly encoded memory representations during sleep as evidenced by the recording of neuronal activity and reported dreams".

While past episodic memory has been shown to be reduced in sleep, the question of mental time travel to the future in REM and non-REM sleep has to our knowledge not yet been formally addressed. This study investigates mental time travel to the future across states of consciousness. Based on the psychological and physiological evidence, we hypothesize that REM sleep and non-REM sleep will exhibit the lowest level of mental time travel to the future when compared with sleep onset and waking.