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The borderlands of waking: Quantifying the transition from reflective thought to hallucination in sleep onset

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ABSTRACT

We lose waking consciousness spontaneously and regularly over the circadian cycle. It seems that every time we fall asleep, reflective thinking gradually gives way to our interactions with an imaginary, hallucinatory world that brings multimodal experiences in the absence of adequate external stimuli. The present study investigates this transition, proposing a new measure of hallucinatory states. *Reflective thinking* and *motor imagery* were quantified in 150 mentation reports provided by 16 participants after forced awakenings from different physiology-monitored time intervals after sleep onset. Cognitive agency analysis and motor agency analysis – which are objective (grammatical–semantic) tools derived from linguistic theories – show (i) a decrease in reflective thinking which sleepers would need to acknowledge the hallucinatory quality of their state, and (ii) an increase in motor imagery, indicating interactions with a hallucinatory world. By mapping these spontaneous changes in human consciousness onto physiology, we can in the long run explore the conditions of its decline, and possibilities for treatment.

1. Introduction

The transition from quiet waking to sleeping involves a variety of physiological changes. These changes involve chemical neuromodulation based on the interaction of aminergic and cholinergic systems, resulting in the hypoactivation of frontal regions, including the dorsolateral prefrontal and orbitofrontal cortex (Fosse, Stickgold, & Hobson, 2001; Hobson, Pace-Schott, & Stickgold, 2000). Cerebral areas are known to fall asleep at different times. It has for example been shown that the left hemisphere has a shorter sleep onset latency than the right (Casagrande & Bertini, 2008; Casagrande, Violani, & Bertini, 1996; Casagrande, Violani, De Gennaro, Braibanti, & Bertini, 1995). On the level of behaviour, we can see a decrease in performance over the course of time with regard to reacting to external stimuli or carrying out repetitive motor tasks, such as finger tapping (Casagrande, De Gennaro, Violani, Braibanti, & Bertini, 1997; Casagrande et al., 1996; Violani, Testa, & Casagrande, 1998).

This study investigates the accompanying psychological and cognitive changes, specifically the transition from reflective thinking towards hallucination: earlier studies suggest that "normal, wake-like thoughts" decrease from waking to sleep onset, to non-REM, and finally REM sleep (Fosse et al., 2001; Speth & Speth, 2016), to be replaced by "unusual thoughts" and hallucinations as multimodal perceptions occurring in the absence of adequate external stimuli (Rowley, Stickgold, & Hobson, 1998; Silbersweig et al., 1995). To complement previous content-based ratings, the present study proposes a new, quantitative measure of hallucinatory states: mentation reports from sleep onset, the physiological markers of which

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were determined by the nightcap sleep monitoring device (Ajilore, Stickgold, Rittenhouse, & Hobson, 1995; Cantero, Atienza, Stickgold, & Hobson, 2002; Stickgold, Malia, Fosse, Propper, & Hobson, 2001), are linguistically quantified via *cognitive agency analysis* and *motor agency analysis.*

We hypothesize that mentation reports collected from later in sleep onset will exhibit a decline in reflective thinking. We further hypothesize that motor imagery, as a positive symptom of hallucinations, will increase over the course of sleep onset: motor imagery can be seen as an indicator of interactions with an imaginative, or hallucinatory, world, or of the (mental) navigation through this world. It has previously been shown that motor imagery differs systematically across sleep states – whereby REM sleep shows highest levels of motor imagery, followed by non-REM sleep, while sleep onset exhibits the lowest levels of motor imagery (Speth, Frenzel, & Voss, 2013; Speth & Speth, 2016). The present analysis should thus reflect an increase in motor imagery as participants transition from sleep onset to non-REM sleep. Mentation reports collected from later as opposed to earlier in sleep onset should contain more references to motor imagery. We will further (a) learn if quantitative linguistic analysis is a feasible tool to investigate mentation during a transitional state of consciousness, and (b) observe the shape of the function of the decline in cognitive agency versus the ascent of motor agency.

The results could pave the way for an improved understanding of the mechanisms of the human capacity for reflective thinking, and the physiological conditions of its decline: the present tool can allow for greater qualitative and quantitative accuracy in mapping the psychological markers of hallucinatory states onto physiological changes – as opposed to merely dichotomous ratings of individuals' mentation during specific states of consciousness as "lucid" versus "hallucinatory" by third person raters. The present measure further brings higher objectivity, reliability, and validity in comparison to investigations that rely solely on the (probably differing) self-evaluations of participants who may exhibit individual interpretations of the abstract, latent variables that are to be tested here (see Speth et al., 2013; Speth, Speth, & Harley, 2015 on the greater qualitative and quantitative accuracy of linguistic tools in quantitative mentation report analysis, and Windt, 2013 as well as Speth, Harley, & Speth, in press, on the crucial distinction between third person ratings of mentation reports versus participants' opinions of their own mental events as obtained via questionnaires). The present measure can potentially be used to reveal the distinct patterns of connected changes in (i) reflective thinking, and (ii) motor imagery, as functions of (iii) physiological changes such as described above.

An improved knowledge of the changes in mentation that occur en route to hallucinatory states could in the long run be beneficial for improved clinical diagnoses and therapy. First, prominent changes in mentation could draw our attention to the connection between distinct physiological changes and specific markers of human mentation, as well as their pathological alterations. An understanding of the distinct interplay of (pathological) physiological changes and human mentation may bring progress in two groups of therapeutic treatment: It may allow (i) for better pharmacological treatment or refined protocols for electrical brain stimulation to target *changes in physiology*. It may also allow for (ii) improved treatment plans in cognitive-behavioural therapy that target *changes in mentation*. A third area of application may be (iii) the combination of treatments targeting changes in physiology as well as changes in mentation, for example in the context of the increasingly popular bio- or neurofeedback systems where acoustic or visual signals of changes in physiology can be used as positive or negative reinforcements of users' mental strategies. Especially spontaneous motor imagery has been shown to lend itself to such manipulation (Speth et al., 2015), and the current measure for hallucinatory states may in the future reveal new opportunities for treatment.

2. Method

Linguistic analysis was conducted on a database of mentation reports from sleep onset. References to reflective thinking and motor imagery were rated blindly. Analysis was conducted with pre-validated tools derived from established grammatical and semantic theories.

2.1. Database

The database comprised 150 reports obtained from sixteen university students (8 male, 8 female). Participants were 19–26 years of age, had provided informed consent, and received financial compensation for participating in the study. Participants were required to complete a preliminary training protocol before asked to deliver oral mentation reports over a fourteen day period. The reports were conceived with a dictation device after instrumental awakenings by a noise signal. Awakenings were initiated by the Nightcap, a sleep-stage detection device that has been shown to reliably detect sleep onset based on changes in eyelid movement patterns (detailed information on the Nightcap database can be found in Stickgold et al., 2001). Reports could thus be collected from quiet waking, as well as 15, 45, 75, 120, or 300 s after sleep onset. The transcribed oral reports were edited according to the technique of Antrobus (1983), which involved removing participants' additional commentary on their mentation.

2.2. Linguistic analysis of motor imagery

Linguistic indications of motor imagery were quantified by means of motor agency analysis (Speth et al., 2013, 2015), a grammatical tool based on linguistic theta theory (Gruber, 2001; Reinhart, 2002; Reinhart & Siloni, 2005). References to