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Original Article

Cyclic alternating pattern in sleep and its relationship to creativity

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ABSTRACT

Background/objectives: Sleep has been shown to enhance creativity, but the reason for this enhancement is not entirely known. There are several different physiologic states associated with sleep. In addition to rapid (REM) and non-rapid eye movement (NREM) sleep, NREM sleep can be broken down into Stages (1–4) that are characterized by the degree of EEG slow-wave activity. In addition, during NREM sleep the cyclic alternating pattern (CAPs) of EEG activity has been described which can also be divided into three subtypes (A1–A3) according to the frequency of the EEG waves. Differences in CAP subtype ratios have been previously linked to cognitive performances. The purpose of this study was to asses the relationship between CAP activity during sleep and creativity.
Methods: The participants were eight healthy young adults (four women) who underwent three consecutive nights of polysomnographic recording and took the Abbreviated Torrance Test for Adults (ATTA) on the second and third mornings after the recordings.
Results: There were positive correlations between Stage 1 of NREM sleep and some measures of creativity such as fluency ($R = .797$; $p = .029$) and flexibility ($R = .43$; $p = .002$), between Stage 4 of NREM sleep and originality ($R = .779$; $p = .034$) and a global measure of figural creativity ($R = .758$; $p = .040$). There was also a negative correlation between REM sleep and originality ($R = -.827$; $p = .042$). During NREM sleep the CAP rate, which in young people reflects primarily the A1 subtype, also correlated with originality ($R = .765$; $p = .038$).
Conclusions: NREM sleep is associated with low levels of cortical arousal, and low cortical arousal may enhance the ability of people to access to the remote associations that are critical for creative innovations. In addition, A1 CAP subtypes reflect frontal activity, and the frontal lobes are important for divergent thinking, also a critical aspect of creativity.

1. Introduction

Fredrich August von Kekule, a famous German chemist, attempted to determine the shape of the benzene molecule, which was known to have six carbon atoms. In 1865, reflecting upon his discovery of the hexagonal-ring-like structure, he asserted that the solution came to him in a dream. "I turned my chair to the fire and dozed. Again the atoms were gamboling before my eyes... My mental eyes... could not distinguish larger structures, of manifold conformation; long rows, sometimes more closely fitted together; all twining and twisting in snakelike motion. But look! What was that? One of the snakes had seized hold of its own tail, and the form whirled mockingly before my eyes. As if by a flash of lighting I awoke..." [1]. Although many people claimed that Kekule fabricated this story, there is no strong evidence to support these doubters and there remains a good possibility that falling asleep did indeed help him solve this problem. Whereas sleep enhanced his creativity, what remains unknown is if he was in rapid eye movement (REM) sleep, dreaming or if he was in Non-REM (NREM) sleep, using imagery.

Sleep is primarily subdivided into REM and NREM sleep. During REM sleep, as the name implies, there are rapid eye movements, decreased muscle tone and a typical electroencephalogram (EEG) pattern characterized by high frequency waves with low voltage. Within NREM sleep there are four different stages primarily defined by the frequency of EEG wave activity. Slow-wave sleep corresponds to the "old" stages three and four [2] or to the "new"

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stage N3 [3], and is characterized by a prominent presence of slow-wave EEG activity (SWA) in the theta and delta range (theta: 4–7 Hz; delta: 0.5–4 Hz). Cyclic Alternating Pattern (CAP) occurs during NREM [4] and is characterized by periodic transient events (phase A of CAP) arising from background activity (phase B). These amplitude changes in the EEG during NREM sleep can reoccur with intervals as long as two minutes. CAP pattern sequences are defined as three or more A phases separated from each other by no more than 60 s. The percentage of NREM sleep occupied by CAP sequences defines the CAP rate. The remaining NREM sleep that is devoid of CAP sequences is called NCAP. This CAP–NCAP dichotomy has been defined as an expression of arousal instability/stability [5].

The A phase of CAP can be subdivided into A1, A2 and A3 subtypes, based on the relative proportions of SWA and faster EEG rhythms. In particular, the A1 subtype is characterized by a prevalence of high-voltage slow waves (EEG synchrony) while the A3 subtype has a preponderance of fast lower-amplitude rhythms (EEG desynchrony); the A2 subtype is a mixture of slow and fast EEG rhythms. A1 is also the most common subtype of CAP, normally accounting for the majority of all CAP A phases during normal sleep, and occurs approximately 200–400 times per night [6,7].

The A1 subtype of CAP is recorded primarily from the leads that are over the frontal and prefrontal regions of the scalp [8]. This distribution of CAP slow waves suggests that they might have a role in sleep-related cognitive processing, and support for this postulate has already been reported [9–11]. It has also been shown that CAP slow components are modified by a learning task during the day preceding sleep [12].

In previous research, CAP activity, particularly A1, has been linked to cognitive activities primarily performed by frontal lobe networks [13]. One of the first steps in the creative process is divergent thinking, and this aspect of creativity also appears to be mediated by frontal lobe networks [14,15]. Therefore, the specific aims of this study were (1) to test the hypothesis that CAP rate during the night is related to creativity during the following day, (2) to test the hypothesis that CAP A1 is positively correlated with measures of creativity, and (3) to test the hypothesis that CAP A2 and A3 are negatively correlated with creativity.

2. Methods

2.1. Participants

Eight self reported right-handed healthy volunteers (four women and four men) with a mean age of 27.8 (SD = 4.31), 16.9 (SD = 2.20) years of education, and no history of neurologic or psychiatric illness served as participants. These participants reported no sleep problems. At the time of this study none of the participants were taking any form of medication. Five out of eight were not cigarette smokers, and the other three participants consumed less than 10 cigarettes/day (two of them less than 5/day). None of our participants were alcohol abusers. See Table 1 for a summary of their demographic information. The subjects' consent was obtained according to the Declaration of Helsinki (BMJ 1991; 302: 1194) and the study was approved by the institution's ethical committee.

2.2. Apparatus and procedures

2.2.1. Overview

The participants underwent a series of three consecutive night polysomnographic recordings at the Sleep Research Centre of the Oasi Institute for Research on Mental Retardation and Brain Aging, Troina (Italy). The first night was used as an adaptation night (data not used for this study). Polysomnographic recordings from the subsequent two nights (Night 1 and Night 2) provided the physiologic data for this study. The participants took a creativity test either on the morning after Night 1 (Morning 1) or on the morning following Night 2 (Morning 2), together with other neuropsychological tests which have been reported elsewhere [13].

Table 1
Demographic and clinical features of the participants included in this study.

	Mean (SD)
Age, years	27.8 (4.31)
Education, years	16.9 (2.20)
Weight, kg	61.8 (8.73)
Height, cm	168.1 (0.63)
Body mass index	21.7 (1.72)
Epworth sleepiness scale	3.4 (1.30)
Handedness	Right = 8, left = 0
Presence of snoring	No = 7, yes = 1 (mild)
Cigarette smoking	No = 5, yes = 3[a]

[a] One subject <10/day; two participants <5/day.

2.2.2. Polysomnographic recordings

All participants were asked to abstain from caffeinated beverages for the duration of the study. Polysomnographic recordings were carried out in a sleep laboratory with controlled sound (noise level to a maximum of 30 dB). Lights-out time was based on the individual habitual bed time and ranged between 09:30 and 11:30 P.M. Participants were allowed to sleep until they spontaneously awoke in the morning.

Polysomnographic recordings included an electrooculogram (EOG, electrodes placed 1 cm above the right outer cantus and 1 cm below the left outer cantus), an electroencephalogram (EEG, 19 channels, electrodes placed according to the 10–20 International System referred to linked earlobes), an electromyogram (EMG) of the submentalis muscle and an electrocardiogram (ECG). Recordings were carried out using a Brain Quick Micromed System 98 recording machine. Signals were sampled at 256 Hz, 12-bit A/D precision and stored on hard disk for further analysis. EEG signals, in particular, were digitally band-pass filtered at 0.1–50 Hz.

2.2.3. Sleep scoring

Sleep stages were scored following standard criteria [3] with 30-s epochs. Subsequently, based on the absence of artifacts, each CAP phase A was detected using the criteria by Terzano et al. [4], from the C3 or C4 electrode. The side of the EEG recording should not influence the detection of CAP, because CAP components have been shown to be symmetric [16].

As mentioned above, CAP is a periodic EEG activity during NREM sleep which is characterized by repeated spontaneous sequences of transient events (phase A), recurring at intervals up to 2 min long. The return to background activity identifies the interval that separates the repetitive elements (phase B). In addition, phase-A subtypes are scored within a CAP sequence only if within 60 s they are followed by another phase A. This is because the CAP procedure is based on the succession of complete CAP cycles (phase A + phase B). Fig. 1 shows a polysomnographic recording with an example of a typical CAP sequence in one of our participants.

CAP A phases have been subdivided into a 3-stage hierarchy of arousal strength: the A1 subtype is an A phase with synchronized EEG patterns (intermittent alpha rhythm in Stage 1; sequences of K-complexes or delta bursts in the other NREM stages), associated with mild or trivial polygraphic variations; the A2 subtype is an A