The Correlation between Sleep and Creativity

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"And if tonight my soul may find her peace
in sleep, and sink in good oblivion,
and in the morning wake like a new-opened flower
then I have been dipped again in God, and new-created."

D.H. Lawrence

Fredrich August von Kekule, a famous German chemist, was attempting 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[1]; however, it is not clear if he was in rapid eye movement (REM) sleep dreaming or if he was in non-REM (NREM) sleep imagery. It is possible to think of this type of discoveries as an expression of creativity, i.e. the ability to use existing pieces of information and combine them in novel patterns leading to greater understanding and new solutions. Preliminary support of the role of sleep in creative thinking comes from a recent study by Wagner et al.[2]; these authors asked normal participants to perform a cognitive task, the Number Reduction Task. In this task, participants are required to understand a set of stimulus-response sequences and supply a single representative numerical answer. Improvement in task performance may be gradual (i.e., by slowly increasing response speed), or abrupt (after insight into an abstract rule underlying all sequences). They found that 59% of the participants that were allowed to sleep were able to perform the task in a time that was 70% shorter than the other group that did not sleep and suggested that sleep may facilitate insight-related problem solving. Here we report the results of

the first study showing a direct complex correlation between sleep architecture or microstructure and creativity in normal controls.

The relationship between NREM sleep and cognitive functions has recently been the focus of intensive research. Oscillatory neuronal activity during NREM sleep seems to be involved in sleep-dependent memory consolidation[3]. Additionally, learning before sleep modulates the regional expression of slow wave activity[4] and spindle density[5] during subsequent NREM sleep, particularly in cortical areas that were initially involved in learning. Interestingly, the regional expression of SWA[4] and spindle density[6] also correlates with overnight improvement in memory performance[7]. Different studies have also given importance to transient or phasic events for different types of off-line memory processing in NREM sleep such as sleep-spindles[5,6], and slow-waves or delta bursts[4,8].

Thus, substantial evidence now suggests that sleep provides crucial mechanisms for memory processing that might be important for functions beyond the consolidation and strengthening of memory traces and might be involved into the offline intelligent assimilation and generalization of them. This might constitute the basis for a hypothetical role of sleep in creativity capabilities[9]; however, a direct correlation between sleep and creativity still needs to be demonstrated.

We have recently reported a significant role for the Cyclic Alternating Pattern (CAP)[10], a physiological component of NREM sleep EEG characterized by periodic transient events (phase A) arising from the background ongoing activity (phase B), in cognitive performance of normal subjects[8,11,12]. In particular, we have shown that the slow-wave containing components of CAP (A1 subtypes) are correlated with better neuropsychological functioning while the other two subtypes (A2 and A3), characterized by increasing levels of rapid EEG activity, are negatively correlated with neurocognitive performance.

CAP A1 subtypes are generated in frontal lobes[13] and are correlated with cognitive activities primarily performed by frontal lobe networks[11,12]; frontal lobe networks also mediate divergent thinking, one of the first steps in the creative process. Therefore, the aims of this study were: 1) to test the hypothesis that CAP rate during the night is related to daytime creativity; 2) to test the hypothesis that CAP A1 subtypes are positively correlated with measures of creativity; 3) to test the hypothesis that CAP A2 and A3 subtypes are negatively correlated with creativity.

Eight right-handed healthy volunteers (4 women and 4 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. The participants underwent a series of 3 consecutive night polysomnographic recordings: an adaptation night followed by two recording nights (Night 1 and Night 2) which provided the physiological 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[12]. We have also already described the details of the polysomnographic recordings[12].

Sleep scoring: Sleep stages were scored following standard criteria[14] with 30-second epochs. Subsequently, based on the absence of artifacts, each CAP phase A was detected using the criteria by Terzano et al.[10], from the C3 or C4 electrode. Figure 1 shows a polysomnographic recording with an example of a typical CAP sequence in one of our participants.

Torrance Test of Creativity: Each participant underwent the Abbreviated Torrance Test for Adults (ATTA) which assesses creative thinking[15]. Our dependent measures included the creative ability scores - fluency, originality, elaboration, and flexibility - from the three tasks of the ATTA. The sum of a series of indicators, added to the scaled scores, forms a composite measure, which is defined as the Creativity Index (CI). The full details on the ATTA are reported elsewhere[15]. The Creativity Index was also recorded and used in our analysis.

For the analysis of the sleep polysomnography recordings, we averaged the targeted sleep parameters, including CAP rate (percentage of NREM sleep occupied by CAP), and percentages of A1, A2, and A3 subtypes, as well as the total sleep time in minutes for NREM Stages 1 through 4 (S1, S2, S3, S4) for Night 1 and Night 2 and total time in REM sleep.

In order to test the hypothesis that CAP parameters are associated with creativity we conducted a series of partial correlations between these selected CAP parameters (see above) and the indices of creativity. Partial correlations were conducted controlling for the effects of both age and education of the participants.

The results indicate that the overall CAP rate was positively correlated with originality scaled score (OSS). The percentage of A1 subtypes was also positively correlated with the total raw score from Task 2. Conversely, the percentage of A2 subtypes was negatively correlated with elaboration scaled score (ESS), total raw score from Task 2, and total raw score from Task 3. Additionally, total time spent in sleep Stage 1 was positively correlated with both fluency scaled score (FSS) as well as flexibility scaled score (FXSS). Total time spent in sleep Stage 4 was positively correlated with OSS and the total raw score from Task 2 (See Table 1). Finally, total time in REM sleep was negatively correlated with ORSS ($r = -.81$, $p = .026$, $R2 = .66$).

The primary findings of our study indicate that CAP is associated with creativity. Specifically, there is a positive relationship between CAP A1 subtypes (containing EEG slow waves) and originality of ideas, fluency and flexibility of visuospatial creativity. In addition, the total time spent in REM sleep

was negatively correlated with originality. These relationships are consistent with expectations (namely, increased slow wave sleep and CAP are associated with enhanced creativity and increased REM is negatively associated with creativity). These results are also consistent with other studies which suggest the importance of slow wave sleep on other forms of cognitive functions, such as learning and processing speed[4,8,11,12].

Our data also indicate a correlation between sleep stage 1 and two aspects of creativity, fluency and flexibility. We are not, however, certain as to why sleep stage 1 would be positively correlated with these aspects of creativity. As we mentioned in the introduction, several scientists have reported that they were able to solve a difficult scientific problem during sleep or when they were falling asleep or awakening from sleep, as well as being in a relaxed state.

We also must consider factors that drive differences in sleep architecture. Stress and emotional state may also be associated with creativity and sleep architecture. Easterbrook[16], as well as Eysenck[17], suggested that stress causes high cortical arousal and this high arousal might suppress the emergence of remote associations. With reduced stress and a decrease in cortical arousal, unusual or remote associations are more likely to become manifest. Further, it has been demonstrated that stress, which increases norepinephrine, results in focused attention on a limited number of external stimuli rather than internal representations (e.g., memories). In addition, stress with increased norepinephrine also may result in a shift in activation of brain networks.

Indeed, studies have revealed that during the time people are anxious they have a reduction of creativity[18]. In addition, patients with a generalized anxiety disorder also have reduced creativity[19]. During NREM sleep there is a reduction of norepinephrine[20] and it is the reduction of norepinephrine that might be a factor in the enhancement of certain elements of creativity. To understand the role of norepinephrine in creativity, Beversdorfet al.[21] assessed its influence on cognitive flexibility by testing normal participants' ability to solve anagrams when treated with placebo, ephedrine and propanolol. Ephedrine increases the level of norepinephrine, whereas propanolol (a beta noradrenergic blocker) interferes with norepinephrine action on the brain. Beversdorf et al.[21] found that people solve anagrams better after administration of propanolol than after administration of ephedrine. In addition, Ghacibeh et al.[22] performed a creativity study of patients who had vagus nerve stimulation for medically intractable partial epilepsy. Their hypothesis was that since vagus nerve stimulation may activate the neurons in the locus coeruleus (LC), potentially increasing the release of norepinehrine, it may result in a reduction in creativity and cognitive flexibility. Their findings were consistent with their hypothesis.

Behavioral support for the postulate that catecholamine-mediated arousal modulates the size of neuronal networks comes from the priming study of Kischka et al.[23] who suggested that dopamine reduces the spread of semantic activation; levodopa is a precursor of both dopamine and norepinephrine, and the administration of levodopa may have also increased the level of norepinephrine in that study.

A long debate is still ongoing on how to classify NREM sleep stage 1. Although this stage has been considered to be part of sleep and thus included into the calculation of the total sleep time, several authors seem to disagree with this[24]. However, in normal conditions, sleep stage 1 is characterized by deep relaxation and a low level of cortical excitability factors. These characteristics may positively influence creativity by allowing greater access to remote associations.

The reason why we found that originality is negatively correlated with REM sleep is not entirely clear. During REM sleep there is physiological evidence of high cortical activation. During this stage, however, the locus coeruleus is even more quiescent than during NREM sleep and the cortical activation appears to be mediated primarily by the cholinergic system. Thus, changes of norepinephrine cannot account for the decreased originality associated with REM sleep.

In addition to accessing remote associations, originality is dependent upon disengagement and divergent thinking. Divergent thinking is the ability to take a different direction from the current and past modes of thought or expression. Denny-Brown[25] proposed that all animals have approach and avoidance behaviors and, at the highest evolutionary level, in humans it is the frontal lobes that mediate avoidance behaviors and the posterior temporal parietal regions that mediate approach behaviors. Thus activation of the frontal lobes would lead to disengagement and divergence and activation of the posterior regions of the brain would do the opposite. Milner and Petrides[26] suggested and provided evidence that frontal lobe dysfunction disrupts divergent thinking. For example, the Wisconsin Card Sorting Task, assesses disengagement and divergent thinking. Milner and Petrides[26] demonstrated that patients with removal of portions of the frontal lobes do poorly on this test because they cannot disengage and use divergent thinking. Thus, these patients “get stuck in set.” There are some studies that indicate a greater posterior than frontal activation during REM sleep[27].

Several studies have investigated the potential role of the frontal lobes in seeking behavior and originality. Comparing participants with high versus low creativity has revealed that the highly creative participants have a higher baseline frontal lobe activity and appear to use their frontal lobes while performing creative tasks[28]. In addition, Chavez-Eakle et al.[29] correlated cerebral brain flow (CBF) with creativity dimensions such as fluency, originality and flexibility, comparing participants with high

and low creativity. Their results indicated that participants with better creative performance showed greater CBF activity in the frontal lobes. Based on Denny-Brown's postulate, we would expect that a predominance of REM sleep activity over the posterior regions would correspond to a decrement of cognitive activities mediated by the frontal lobes which would interfere with originality on creativity tests.

That CAP A1 activity is positively correlated to performances on Task 2 of the ATTA and CAP A2 is negatively correlated to performances on the same test as well as on Task 3, might also be explained by the same frontal-temporo-parietal approach avoidance dichotomy. CAP A1 activity is generated primarily by the frontal lobes and CAP A2 and A3 activity is generated by the posterior brain regions.

While the nature of the relationship between CAP and creativity is unclear, it may be driven in large part by the A1 subtypes. All of our participants were young and it is known that CAP in young people is mainly represented by the A1 subtypes[30].

To our knowledge, this is the first study specifically designed to examine relationships between sleep stages or CAP and creativity and reveals several apparently strong and important relationships; future research to explore in depth these relationships is warranted.

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Table 1. Bivariate correlations between the creativity and sleep structure or CAP variables. Each cell of this table contains correlation coefficient and (p value).

	CI	FSS	OSS	ESS	FXSS	ACT1	ACT2	ACT3
CAP rate	.542 (.133)	.040 (.470)	**.765** **(.038)**	.476 (.170)	-.219 (.338)	.409 (.210)	.515 (.148)	.231 (.330)
A1%	.632 (.089)	.323 (.266)	.195 (.356)	.567 (.121)	.472 (.172)	.013 (.490)	**.809** **(.026)**	.540 (.134)
A2%	-.617 (.096)	-.179 (.367)	.058 (.456)	**-.753** **(.042)**	-.546 (.131)	.260 (.309)	**-.825** **(.022)**	**-.731** **(.049)**
A3%	-.379 (.229)	-.404 (.213)	-.501 (.156)	-.031 (.477)	-.152 (.387)	-.429 (.198)	-.432 (.196)	-.010 (.493)
S1	.457 (.181)	**.797** **(.029)**	-.148 (.390)	.353 (.247)	**.943** **(.002)**	.039 (.471)	.121 (.409)	.618 (.096)
S2	-.238 (.325)	.069 (.448)	.128 (.405)	-.318 (.270)	-.262 (.308)	.391 (.221)	-.696 (.062)	-.276 (.298)
S3	-.418 (.205)	-.595 (.106)	-.263 (.307)	-.105 (.421)	-.349 (.249)	-.589 (.109)	-.102 (.424)	-.207 (.347)
S4	.689 (.065)	-.008 (.494)	**.779** **(.034)**	.632 (.089)	-.221 (.337)	.439 (.192)	**.758** **(.040)**	.340 (.255)

CI = creativity index; FSS = fluency scaled score; OSS = originality scaled score; ESS = elaboration scaled score; FXSS = flexibility scaled score; ACT1 = Activity 1; ACT2 = Activity 2; ACT3 = Activity 3. Correlations coefficients printed in **bold** typeface are statistically significant ($p < .05$).

Figure legend

Fig. 1. Example of CAP during sleep stage 2 of one participant; three A1 subtypes are shown, along with one A3 subtype. Also the scalp topographic mapping of the EEG slow-wave component of one A1 subtype is shown, together with the scalp topographic mapping of the EEG high-frequency component of the A3 subtype, obtained as already reported by Ferri et al.[18] in 2005.