Brain Activation and Cognitive Load during EEG Measured Creativity Tasks Accompanied by Relaxation Music

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Abstract: Creativity tasks require specific imagery, memory and semantic processes, as it has been revealed by various neuroscientific studies. There is significant evidence that an increase of spectral power in the EEG alpha band is inter-related with creative ideation as a form of top-down activity. However, any creational task demands a certain level of cognitive load or workload for memory retrieval, mental schemes design, semantic processing, image formation and concept construct. This paper aims to measure cognitive load during a series of divergent thinking creative tasks accompanied by relaxation music, to examine event-related brain activation and raw power measures in the baseline relaxation, alternate uses creative and verbalization stages of the proposed experimental procedure, as well as to study task-related synchronization/desynchronization between these phases. Also, its purpose is to verify whether slow relaxing music influences creativity, with effects in the brainwaves amplitude variations, especially in the alpha (8-12 Hz) frequency band. We concluded that relaxing music induces creativity and causes an increase in the alpha brain waves for innovative ideas generation and verbalization with a diminished level of cognitive load.

1 INTRODUCTION

Along with mental constructs such as intelligence, creativity is an important asset of the human psychological profile, with applicability for producing original and innovative work in a wide range of scientific domains, for social communication and interaction or for achieving various lifetime proposed goals (Fink & Benedek, 2012, Smith 1995). Creativity has been studied within many experiments requiring completion of different types of originality tasks, among which a notable position is reserved to the divergent production alternate uses tasks, where participants are asked to bring original and unconventional solutions or explications to common notions or concepts (Arden 2010). This type of task involves retrieval of existing knowledge from the memory and (re)combination of it into singular ideas (Paulus and Brown, 2007), generating diversified approaches in manifold ways, as opposed to convergent thinking that brings about only one straight solution. There are many neuroscientific studies that have analysed brain activity during creativity tasks, considering spectral power activation within the EEG bands, event-related potentials (ERP), event-related synchronization/desynchronization (ERS/D) or functional connectivity between different cortical areas – coherence and phase lag. The alpha band is the most sensitive band in relation with creativity demands – there is higher alpha power in the posterior regions of the brain during activation periods as compared to baseline resting stages (Jausovec, 1997), in the central and parietal areas (Molle, 1999), posterior regions of the right hemisphere during divergent, free-associative thinking tasks than in the convergent ones (Shemyakina, 2007) and in the posterior cortical areas (parietal and parietoocipital) in the alternate uses procedure (Fink, 2009). Also, more original ideas conduct to higher right hemisphere alpha synchronization (Grabner, 2007, Martindale, 1984). Increases in the parietal and occipital areas is associated with higher cognitive load, memory

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search, retrieval and semantic associations, increased focus on goal-directed tasks, diverting irrelevant stimuli, internal mnemonic representations or memory retrieval according to the purposes of the user – top-down activation in the absence of bottom-up stimulation (dorsal parietal) (Cabeza, 2008, Jensen, 2002). The right hemisphere is dedicated to imagery and association of unrelated semantic concepts (Bowden, 2003). Alpha synchronization appears also in the prefrontal cortex, especially in the right hemisphere (Hietanen, 1998), reflecting high processing demands (Benedek, 2011) and increased attention (Knyazev, 2007). The results from (Punsawad et al, 2014) showed increased levels of alpha and theta during creational tasks in the right frontal areas (channel F8).

Cognitive load theory states that working memory is limited in regard with the quantity of information that can be kept in mind at a moment of time and to the ability of processing and combining novel knowledge (Antonenko et al, 2010, Peterson, 1965). EEG measurements revealed that alpha desynchronization is associated with increased attention and cognitive load in the parietal areas (Gevins, 1997). Also, it is related to searching and retrieving information from the long-term memory. Theta synchronization on the other hand is related to task difficulty and emotional factors, especially in the frontal midline locations (Klimesch, 2005, Gevins, 2000) and is associated with episodic and working memory processes. Delta power increases also during complex mental tasks in the temporal regions (channels T7 and T8), demonstrating the amount of attention given by the user to internal information processing (Dolce, 1974), while low beta bands have synchronized powers in the frontal midline areas (Klimesch, 1999)

Gifted individuals exhibit higher alpha power changes (high level of relaxation) and activation in the frontal cortical area, whereas hard working subjects present low level alpha synchrony, particularly in the temporal regions (O'Boyle 1995). In (Antonenko et al, 2010), video and picture presentation activated the occipital and temporal lobes (responsible for visualization), while text presentation, the frontal one (assigned to verbal processing).

2 PROPOSED METHOD

Our study proposes an alternate uses divergent thinking set of tasks, in which the subject is required to think about uncommon uses for 5 different words - pencil, brick, key, paper clip and shoe, while listening to slow relaxing music. The first step is represented by the fixation cross to which the subjects have to look for a time period of 10 seconds. This step will be referred to as *reference* (or calibration, to record baseline brain activity) because this time interval aims to be reference interval for the EEG activity. Secondly, a stimulus word was shown for 5 seconds. The subjects were given instructions to be as innovative as possible and to come up with different usages than the common one for the displayed object. The next step is represented by the uncoloured bulb image, 30 seconds of *creative thinking time* for the participants. During this step, the subjects were prior instructed not to verbalize their answer yet, but only to think of original uses of the previously seen stimulus. Simultaneously, the subject was provided relaxation music via headphones. The final phase is represented by the coloured bulb image, which lasts for 10 seconds, time in which the participants had to *verbalize* their creative ideas (Figure 1). *Verbalization* has been chosen over listing because it takes less time and is simpler for participants, the emphasis being on the idea generation process. The task requires 55 seconds to be completed. Each of the subjects performed the task five times, once per stimulus word.

Figure 1: The experimental procedure.

3 THE EXPERIMENT

3.1 Subjects

The study was performed on six subjects (four females and two males) aged 21-29, five undergraduate students and a teacher. The subjects were orally informed about the purpose of the experiment, were provided instructions and gave their approval consent before the start of the tests.

3.2 Data Acquisition

The hardware devices used to capture EEG signals through the non-invasive method were the Brain Products actiCAP Xpress Bundle set together with V-Amp 16ch amplifier (Acticap website). The software used for EEG acquisition was OpenVibe for Brain Products (Open Vibe website). All the signals were sampled at a frequency of 512 Hz, as it is the optimal sampling rate for analysing resting EEG (Jing & Takigawa, 2000). The used electrodes positions were: fronto-parietal left (FP1) and right (FP2), fronto-central left (FC1) and right (FC2), central left (C3) and right (C4), temporal left (T7) and right (T8), parietal left (P3) and right (P4) and occipital left (O1) and right (O2). Furthermore, 4 midline electrodes were used (Fz, Cz, Pz, Oz). Electrodes impedances were kept below 10 kΩ in order to minimize the noise and artefacts in the data. The recorded data was bandpass filtered between 0.5-100 Hz.

3.3 Data Acquisition

The term EEG artefact refers to recorded electrical activity whose origin is non-cerebral. Depending on its origin, these artefacts are split into physiological and non-physiological artefacts. The first category is generated from the body (other than the brain), while the second one from outside the body. Blinking, eye movements, muscle activity, body or head movement, cardiac, pulse waves, they all represent examples of the physiological artefacts. Some of these can be recognized. Non-physiological artefacts are caused by either electrical interference with other power sources or the abnormal functioning of the recording equipment. A typical electrical interference artefact present in EEG recordings has as source power lines and equipment. This artefact has a 50/60 Hz frequency. Our signals were DC-offset corrected in order to prevent the influence of voltage imbalance issues and powerline contamination was removed using the notch filter. Blinking, cardiac and muscle activity artefacts, together with the bad channels were automatically removed using the Brainstorm software (Tadel et al, 2011). Independent Component Analysis has been performed in EEGLAB (EEG LAB website) in order to separate independent sources, reject artefacts and identify brain related activity in coloured topographic maps.

3.4 Power Spectrum Analysis in Frequency Bands

The information was extracted for the last step which is statistical analysis. Firstly, the data that is to be statistically analysed requires having the same length. Currently, most of the recordings have around 55 seconds, -4/+15 seconds, according to the number of inputs the subjects were having in the verbalization phase. Given the interest in studying how the brain waves change in the divergent thinking phase, as stated in the hypothesis, the signal was split such as the reference phase may be compared with the other phases. Therefore, the signal was split as follows - from a time window perspective: [0 10] for the reference phase, [15 25], [25 35] & [35 45] for the creative thinking phase and [45 55] for the verbalization phase. Extracting all these intervals was done manually in EEGLAB. After being split into intervals, the EEG recordings were imported in Brainstorm where further processing steps were taken.

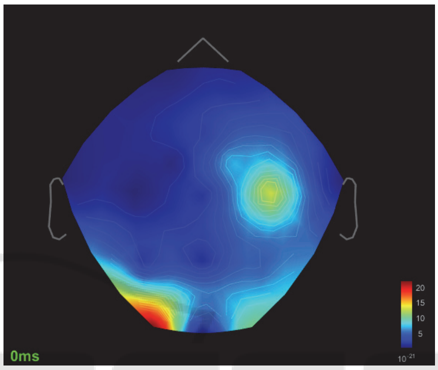

Figure 2: Power spectral analysis for Resting period - averaged response across all subjects.

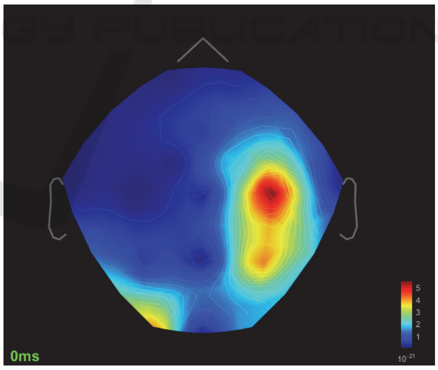

Figure 3: Power spectral analysis for Creative Thinking period - averaged response across all subjects.

Considering the averaged responses for all the subjects, alpha activity was prominent as follows: in the resting phase - in the left occipital region (Figure 2), in the creative thinking phase – in the right parietal area (Figure 3), while in the verbalization stage – in the right parietal and left occipital regions (Figure 4). Similar patterns are observed in the theta band, with the only difference that in the verbalization phase, activation is prominent only in the right parietal cortical area and to a lower extent in the left occipital region, demonstrating the slight influence of visualization in verbal tasks. Alpha synchronization occurs in the right parietal area and desynchronization is evident in the occipital region in the thinking stage, as compared to resting baseline.

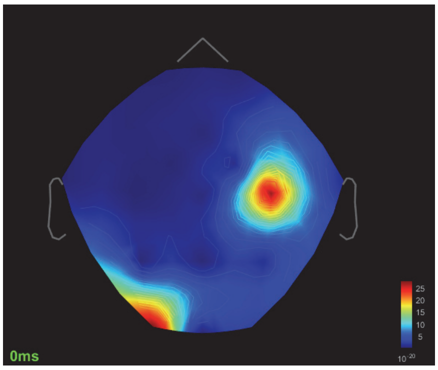

Figure 4: Power spectral analysis for Verbalization period - averaged response across all subjects.

3.5 Statistical Analysis

Even though fluctuations over time in the alpha waves can be noticed by examining the time-series for a signal time-frequency decomposition, in order to formalize the results and to be able to actually draw conclusions, a statistical analysis needs to be performed. Another reason for performing this analysis is represented by the number of data that would require a thorough individual analysis to reach a global study result.

Taking into consideration the hypothesis: “There is a significant change in alpha activity during a creative activity as compared to a non-creative one”, the study aims to evaluate whether creativity causes an increase in the alpha brain waves through a given divergent thinking task and a statistical hypothesis test is applied to check whether there is a significant difference between the two phases. The data was analysed in a parametric Student t-test and 2D topography of the results was plotted.

30 files (10 seconds duration) resulting from resting baseline recording were compared to 90 files (10 seconds duration each) from the creativity task recording. The results show significant differences in the left fronto-central cortical area at $p<0.13$ where the mean of the alpha power in the creative thinking condition is higher than in the resting phase. Taking the first test scenario, reference (A) vs. thinking (B) phase and the previous explanations, the results are statistically significant in the direction of condition B (blue) represented by the thinking phase in this scenario. The confidence level for these tests is close to 90%. The results of this study prove that indeed creative ideas generation is associated with the growth of the alpha activity in comparison with the reference period (Figure 5).

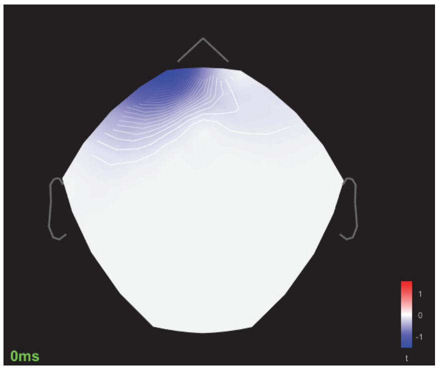

Figure 5: Student t-test. Reference (A) vs Creative Thinking (B), $p < 0.13$.

Figure 6: Student t-test. Verbalization (A) vs Creative Thinking (B), $p < 0.01$.

30 files (10 seconds duration) resulting from verbal recordings were compared to 90 files (10 seconds duration each) from the creativity task recording. The results show significant differences in the left fronto-central and right parietal and temporal cortical areas at $p<0.01$ where the mean of the alpha power in the verbal condition is higher than in the creative thinking phase. Given the fact that the critical level for the verbalization vs. reference test is lower ($p < 0.01$) than the one of thinking (B) vs. reference (A) phases ($p < 0.13$), and that the regions where alpha activity presents significant changes are identical, we would expect that in the verbalization phase the alpha activity is increased as compared to thinking phase. Figure 6 proves a remarkable increase in the alpha activity in the frontal and temporal lobes as well as in the

central region, to be more specific, in the frontal left hemisphere - especially frontopolar (FP1) and in the temporal (T8) and central (C4) right hemisphere (Figure 6).

The values displayed in the 2D test result views (Figure 5 & 6) represent the significant t-values, the sensors that have the value of $p > \alpha$ being set to 0. We may state that for those 'white' brain regions the hypothesis is likely to occur → the null hypothesis (H0) is not rejected, thus no significant changes occur in the alpha waves. The two-tailed tests establish whether the difference between the two groups, A and B, is statistically significant in either the positive or negative direction (Frost, 2016) In the figures, the red values represent a higher amplitude for condition A, while the blue values for the condition B.

Quantitative EEG (QEEG), as the measurement of the electrical brain activity and connectivity between different areas, offers substantial and valuable information about the dynamic changes of brain activation, interrelation, engagement and overload of various areas. Brain connectivity refers to coherence analysis (correlation between different brain areas) and phase lag (speed of information transfer on the cortex and rate of data transfer).

The results showed high correlation in the frontal area (FP1 x FP2), parietal and temporal regions (P3 x P4, P3 x T7, Pz x T7, Pz x P3). High rates of data transfer (high values of phase lag) occur in the frontal regions for the theta band (FP1 x FP2) and in the left frontal, parietal and central areas for the alpha band (FP1 x C3, C3 x Pz, T7 x C3, FC1 x C3, FC1 x FP2, P3 x P4, P3 x T7).

4 DISCUSSION

In a creativity related brain activity study, the answers of subjects that were more innovative positively correlated with lower alpha (8 - 10 Hz) amplitudes mainly in the left hemisphere. The same study also shows desynchronization in the central and posterior regions, but not in the frontal one (Razumnikova, 2007). Taking into account the results of the aforementioned study which also state that highly original responses generated increased event-related synchronization in the left hemisphere for the low alpha band (Haarmann et al, 2013), we may make the assumption that the increased alpha activity in the left hemisphere is correlated with higher originality in the subjects' answers.

Beta synchronization in the frontal and midline regions are indicators of cognitive load. In our study, alpha synchronization occurs for all the frequency bands and beta desynchronization is visible in the frontal and midline areas. Also, there is no significant difference between the resting and creative task for the theta and delta bands. Thus, we conclude that the level of cognitive workload is reduced during alternate uses divergent thinking tasks as far as it concerns the delta, theta and beta bands and that a sign of activation is visible only for the alpha band, indicating memory retrieval and attentional demands. However, as far as it concerns the averaged responses across all subjects and trials (Figure 3), alpha synchronization is visible in the creative thinking phase in the parietal area and less visible in occipital area.

One aspect to discuss is the value of the p-value threshold. To increase the accuracy of the statistical tests, the p-value threshold could have been decreased, mainly for the reference vs thinking groups test, however, the results would not have shown this significant information if done so. Moreover, a larger sample size will normally lead to a better estimate too. The eventual presence of physiological artefacts, the possibility of not having the phases according to such strict time intervals as defined in the experimental task, and not having the ability to check precisely whether the subjects are following the instructions for the first 45 seconds (especially thinking creatively for the whole 30 seconds interval) of the EEG recordings, they all contribute to eventual discussions on test's accuracy.

5 CONCLUSIONS

The aforementioned findings allow us to validate the study hypothesis which states that there is a significant change in alpha activity during a creative activity as compared to a non-creative one. Through giving the subjects an alternate uses task which aims to measure divergent thinking while listening to relaxing music and recording their brain activity, it was evaluated and concluded that creativity causes an increase in the alpha brain waves in the innovative ideas generation as well as in their verbal expression phases with a diminished level of cognitive load.

Further research concerns encompass increasing the number of subjects and trials per experiment in order to obtain higher statistical significance and designing an experiment where the subjects will be required to listen to different music genres or semantically significant ambient sounds connected to the meaning of the word they have to creatively think about.

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