Resting State Brain Dynamics Supporting Creativity

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ABSTRACT

Creativity is often seen as the expression of fluid thought and defined as the ability to generate original, useful contributions to human endeavors in the form of new ideas, representations, material objects, and so forth. This study examines how different types of virtual search tasks can impact creative thinking, as well as neurodynamics conducive to creative thought. In particular, we examine how a task that involves open-ended exploration modulates resting state electroencephalographic (EEG) alpha power (8 - 12 Hz) relative to a task that simply involves following a series of instructions. Our results indicate that alpha power variability is linked to task-related changes in performance on the Alternative Uses Task (AUT), which is a psychometric measure of creative abilities allowing for an operational measurement of creativity. This study advances our understanding of human creativity from a neurocognitive perspective.

I. INTRODUCTION

Psychologists have linked scope of attention to aspects of information processing that support insight and creative thought (Carson et al. 2003; Rowe, Hirsch and Anderson 2007). *Broad* or *diffuse* attention is characterized by less efficient inhibition or filtering of task-irrelevant information, leading to the greater likelihood that disparate concepts come to be connected. This contrasts with *narrow* or *focused* attention, where there is less frequent connection of differing concepts. Individuals distinguished by higher levels of diffuse attention (Kasof 1997) or lower latent inhibition abilities (Carson et al. 2003) have been associated with superior immediate and long-term creative achievement, respectively. Further, visual search tasks have led to improved scores on measures of creative thought when targets and distractors are scattered over a large versus small display field, eliciting broad or narrow attentional mode, respectively (Friedman et al. 2003).

Electroencephalography (EEG) is a method that is used to record the electrical activity of the brain through non-invasive electrodes applied to the scalp. Thus far, several studies have indicated a relationship between the topography and magnitude of resting state EEG power, and the likelihood of experiencing insight (Kounios et al. 2006. 2008; Wu et al. 2014). Kounios et al (Kounios et al. 2008) demonstrate that during rest, spectral activities in the alpha frequency band (8 – 12 Hz) tend to be diminished over the right hemisphere in people who experience insight more often. Alpha power represents alpha waves, one of the numerous types of brain waves recorded through EEG, and is most prominent during times of wakeful relaxation (Klimesch, 1999). Because suppression of alpha power is linked to cortical excitation (Klimesch, 2012; Lin et al. 2015), this outcome may reflect more engagement of visual cortex on the part of high insight problem solvers.

Our project investigated whether creative thinking abilities can be at least transiently enhanced by participating in virtual reality based tasks. These tasks are designed to stimulate either a broad or narrow focus on the participant's virtual environment, such that changes in resting state EEG dynamics that might accompany modulations of creative abilities could be analyzed. In the task that stimulates broad attention, the participant was prompted to discover a creative solution to the problem at hand, whereas in the task stimulating narrow attention they followed a series of instructions. By understanding more about brain states that support creativity, it may be possible to develop neurofeedback training protocols to enhance creative abilities or predict optimal periods for creative work on the basis of resting state EEG. **Solving the discovery-based task is expected to lead to changes in resting state alpha activities relative to the instruction-based task.**

II. METHODS

A. Participants

The Institutional Review Board of UCSD approved this experiment protocol. Twenty-three volunteers were compensated for their participation at a rate of $15.00 per hour. All were neurologically healthy university students who gave informed consent.

B. Materials

A 14-channel wireless Emotiv Epoch headset was used to collect EEG data. The game development platform, Unity, was used for the virtual reality tasks. Unity was chosen over other platforms due to its capacity for creating high-quality 3D games through which to present the scenarios of broad and narrow attention for both the "creative game" and "control game" conditions, respectively. Both game scenarios involve participants getting into the house, but they were prompted to do so differently in each condition. In the "control game," participants were asked to follow directions on a series of notes that led them to a key used to unlock a door. In the "creative game," they were asked to discover a way to break into the house.

The instrument used to evaluate creative thinking was the Alternative Uses Task (AUT) (Torrance 1966). In brief, the AUT is a widely used test of divergent thinking that requires participants to enumerate as many novel uses for a conventional item (e.g. a paper clip) as possible within a fixed time. Fluency scores were determined by recording how many unique uses each participant produced for a given item, and were assessed for AUT sessions administered both before and after each virtual reality task. Differing fluency scores after each VR task would indicate a change in levels of creativity as a result of completion of the control or creative task, where a higher fluency score indicates a higher level of creativity.

C. Procedure

Each subject participated in two experimental sessions, with one session involving the control, instruction-based game and the other involving the creative, discovery-based game. Two scenarios were created using Unity – each tasking the player with finding a way to enter a locked house after having lost the key. In the narrow attention version, the player followed a trail of notes with instructions where to look for a hidden key. In the broad version, it was necessary to discover alternative entry points and devise methods for accessing them using serendipitous tools in the environment. The order of these sessions was counterbalanced such that the instruction- and discovery-based games were presented in alternating orders across individuals, with intervals between sessions ranging from 3 to 31 days. Participants received oral and written instructions for each task. A 3-minute resting state pre-game baseline EEG was recorded at the start of each session, followed by the first AUT session. The participants then played either the instruction- or discovery-based computer game for 15 minutes, and a 3-minute resting state post-game baseline EEG was recorded following the game, and followed by the second AUT session. The four words used for the AUT were "paperclip", "brick", "button", and "newspaper". The order of these words were counterbalanced by incorporating a random number generator into the script of the experimental program in order to present a randomly selected word during each of four trials for each subject without repetition of any of the AUT words. Over the course of their two sessions, each participant was presented all four of the words amongst the AUT sessions preceding and following both the "control" and "creative" games.

D. Data Acquisition

EEG data were recorded over 14 scalp locations using the wireless Emotiv Epoch headset with a sampling rate of 128 Hz. AUT responses were recorded using a voice recorder before being manually transcribed for each session.

E. Behavioral Data Analysis

A fluency score was obtained for each participant's AUT session by counting the number of responses for each session. Participants whose fluency scores improved after the creative game were separated from those whose fluency scores decreased for analysis of their EEG power spectra.

F. EEG Analysis Preprocessing: EEG signals were analyzed using MATLAB (The Mathworks, Inc.) and the open source toolbox, EEGLAB (Swartz Center for Computational Neuroscience, University of California San Diego). EEG time series data were inspected visually to exclude poor-quality channels. Next, data from baseline rest periods were extracted from the full dataset and divided into one-second segments. Segments of data heavily contaminated by movement and other non-brain artifacts were identified and excluded via EEGLAB algorithms sensitive to statistically improbable values. Thirteen subjects were eliminated from this analysis because it was not possible to obtain clean data for both the Emotiv O1 and O2 channels located above the occipital lobe area.

2) Pre- and Post-Game Baselines: Out of the 14 Emotiv Epoch channels, channels O1 and O2 were selected for further analysis of the pre- and post-game baseline EEG (Figure 1) because these channels presented the lowest levels of EEG background noise and were clean for the majority of the participants. Estimates of power spectral density were computed from baseline rest EEG (3 to 50 Hz) and graphed for each subject. Mean power spectra for alpha level frequencies (α: 8-12 Hz) were computed by averaging power estimates within this frequency range.

III. RESULTS

A. AUT Fluency Scores

After the discovery-based problem solving task, four participants generated more alternative uses relative to their pre-game baseline, whereas six participants generated fewer. Mean fluency scores, defined as the mean number of words produced per three minute session, from these two groups were analyzed separately (Table 1a, 1b). The group whose fluency score decreased or increased following the "creative game" will be referred to as the "decrease in fluency scores" versus the "increase in fluency scores" group, respectively. The "decrease in fluency scores" participants also showed a decrease in fluency following the instruction-based task. The "increase in fluency scores" participants also showed an increase in fluency following the instruction based tak. However, the fluency scores decreased or increased by a larger magnitude following the “creative game” compared to following the “control game” for both groups.

	Control	Creative
Pre	11.7 (9.4)	11.7 (3.9)
Post	10.3 (4.8)	9.7 (4.7)

Table 1a. Mean fluency scores with standard deviation in parentheses for “decrease in fluency scores” participants before and after the control and creative problem solving tasks.

	Control	Creative
Pre	8.3 (5.6)	6.5 (1.3)
Post	9.8 (4.3)	11.5 (4.5)

Table 1b. Mean fluency scores with standard deviation in parentheses for “increase in fluency scores” participants before and after the control and creative problem solving tasks.

B. Resting-state Dynamics

Figure 2 and Figure 3 plot grand averages of resting-state spectral power derived from left and right occipital EEG (O1 and O2, respectively) from the ten participants with clean O1 and O2 channel data. Over the left occipital channel, alpha power gained in magnitude after the discovery-based task for all participants; however the magnitude of this gain was greater for the increasing fluency scores group (Figure 2). This effect appears confined to the left hemisphere (Compare Figure 3 with Figure 2).

IV. DISCUSSION AND CONCLUSIONS

This study yielded three noteworthy findings. First, discovery-based problem solving led to increased resting-state alpha activity levels centered over the left occipital region of the scalp, whereas minimal pre-post differences for either group were detected over the right occipital homologue. This finding suggests an important role for the left-hemisphere in supporting aspects of creativity. In our study, resting state alpha power of the increasing fluency group tended to be higher after the participants were tasked with discovering a game solution versus simply following directions. On the other hand, pre- versus post-game levels of resting state alpha were comparable irrespective of task for the decreasing fluency group. This pattern of outcomes is consistent with other research suggesting that alpha activities tend to increase during creative thought, perhaps reflecting more internally versus externally focused attention (Fink and Benedek 2013). Importantly, though, the overall levels of resting-state alpha power were higher for the decreasing fluency group relative to those whose fluency scores actually benefited from the discovery-based task. In other words, the upward shift in alpha power appears more important than overall magnitude.

It is noteworthy that the pattern of outcomes described here differs substantially from outcomes described in related studies, such as that of Kounios et al (Kounios et al. 2008), who reported reduced rather than enhanced alpha power and greater right rather than left hemisphere effects in participants who tended to solve puzzles with insight. One explanation for these disparities relative to the present study centers on the differences in experimental tasks. In Kounios (Kounios et al. 2008), participants were asked simply to solve a series of anagram puzzles. In the present work, the task involved multiple possible solutions and an open-ended search space. Importantly, while the right hemisphere has traditionally been implicated in insight (Jung-Beeman et al. 2004) and semantic processing (Coulson and Wu 2005) that could support creativity, it appears that right hemisphere engagement is not always crucial during creative problem solving.

These findings supplement our understanding of human creativity and its corresponding electrical activity levels present in the brain. Using findings from this and similar studies, neurofeedback training protocols involving alpha wave stimulation can be developed to enhance creative thinking, and ideal periods for creative work can be predicted, in keeping with existing techniques (Gruzelier 2014). This study also exemplifies the utility of 3D gaming as a tool to stimulate problem-solving.

Next, we plan to perform the experiment with an EEG cap capable of recording 128 channels in order to obtain both more abundant and cleaner data in comparison to the wireless Emotiv Epoch. We also plan to score the AUT for originality, flexibility, and elaboration to supplement the fluency scores in order to determine how these other aspects of creative thinking are linked to resting state EEG.

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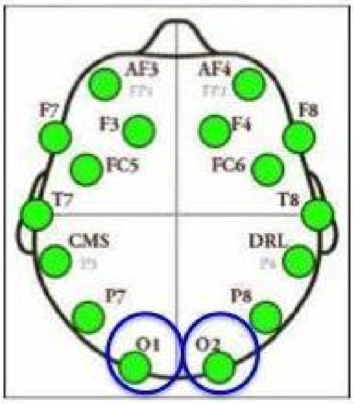

Figure 1. Scalp locations of O1 and O2 channels

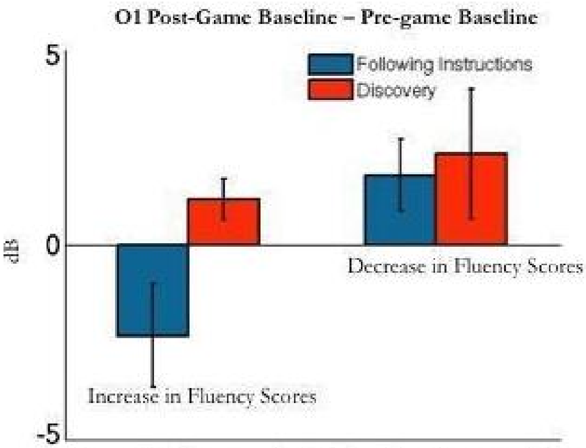

Figure 2. Differences obtained by subtracting mean alpha power on pre-game baseline from post-game baseline over the O1 electrode for each participant. Positive values reflect greater power on post-game versus pre-game baselines; negative values, the reciprocal.

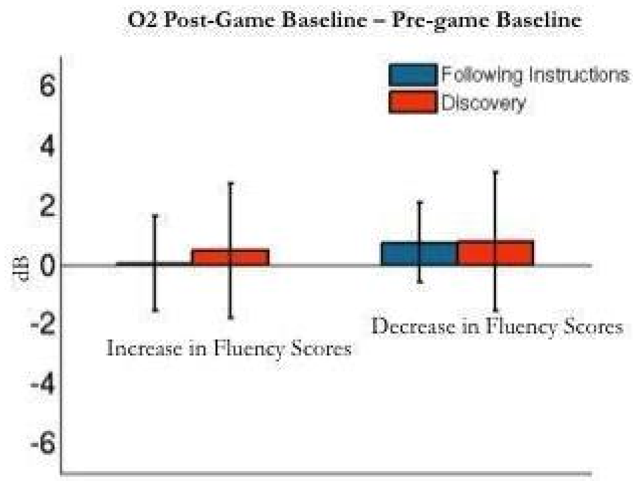

Figure 3. Differences obtained by subtracting mean alpha power on pre-game baseline from post-game baseline over the O2 electrode for each participant. Positive values reflect greater power on post-game versus pre-game baselines; negative values, the reciprocal.