Workshop Paper

Studying The Neurophysiology of Designing Through an EEG Study of Layout Design: Preliminary Results

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ABSTRACT

The study described in this workshop paper is part of a larger research project whose goal is to correlate design cognition with brain behavior. This paper presents preliminary results from an experiment using EEG to measure brain activation to study design cognition. In this study, we adopted and then extended the tasks described in a previous fMRI study of design cognition reported in the literature. The block experiment consists of a sequence of 3 tasks: problem solving, basic design and open design using a physical interface. The block is preceded by a familiarizing pre-task using the physical interface and then extended to a fourth task using free-hand sketching. We have collected brainwaves in experiments with 44 participants with backgrounds in industrial design, architecture, engineering design and graphic design. This paper shows preliminary neurophysiological results from 12 participants, comparing industrial designers and mechanical engineers. Preliminary results indicate task-related power differences in activation between the problem- solving task and the design tasks, differences in band power levels and temporal resolution across participants and across backgrounds. The results from this study will contribute to the correlation of brain behavior during designing with design cognition.

1. BACKGROUND

The understanding of the neurocognitive processes of design is still in its infancy. Design cognition functional magnetic resonance imaging (fMRI)-based studies are at the exploratory stage with one well-controlled experiment published (Alexiou et al. 2009). The application of electroencephalography (EEG) and the development of readily available software as a research tool has increased, partly due the reduction in the cost of the equipment. This has made the collection and analysis of EEG signals a viable option for design researchers. Design cognition EEG-based studies are also at an exploratory stage with only a few reported studies on engineering design and architectural design. Results from controlled experiments identify EEG bands associated with the design activities of problem solving and evaluation (Liu et al, 2016), neurophysiological EEG signals to study effort, fatigue and concentration in conceptual design (Nguyen et al. 2016), and neurophysiological correlates of embodiment and motivational factors during the perception of virtual architecture (Vecchiato et al. 2015). Results open the way for researching the distinctive nature of design. The use of EEG allows the precise measurement of rapid changes in neural activity related to observable stimuli, making it possible to assess the timing of task-relevant cognitive operations and to separate component processes in the stream of information processing (Stern, Ray and Quigley, 2001). EEG can provide high temporal resolution during cognition that can help elucidate the stages of the participant recognition of tasks and provide the temporal basis for information processing (Hinterberger et al. 2014). Averaging the measurements yields a measure of the EEG voltages that are consistently related to the sensory, perceptual and decision-making processes that followed the stimulus in the task experiment (Dickter and Kieffaber, 2014). In the field of psychology, the study of creativity (Fink et al. 2009a, Fink et al. 2009b) has advanced to time-related neural responses during the process of creative ideation (i.e., the generation of creative ideas) and to the patterns of EEG alpha power and its changes (Schwab et al. 2014; Rominger et al. 2018). However time-related neural responses during problem solving compared to design tasks are as yet unknown. Studies of insights based on neuroscience techniques are valuable for design research as the higher activation of the dorsolateral prefrontal cortex is consistent for design tasks and ill-structured problems (Alexiou et al. 2009), and insight (Kounios and Beeman 2009, Beeman et al. 2004), and recruits a more extensive network of brain areas than problem solving (Alexiou et al. 2009, Kounios and Beeman 2009). In the context of creative cognition, it is argued that the two brain hemispheres do not always process information in the expected manner (Goel, 2014a) and that it is the task rather than the stimuli that determines the mode of processing (Springer and Deutsch,1998; Stephan et al. 2003). Others argue that what engages the left and right hemispheres respectively is the extent to which a situation involves the engagement of routine versus novel cognitive strategies (Goldberg, Podell and Lovell, 1994). It has also been suggested that creative cognition studies with focus on insight and divergent thinking problems, may not be particularly central to understand creativity in the context of designing artifacts for the real world (Goel, 2014a). In the current research we aim to develop an understanding of the cognitive neural processes of designing by taking the advantages of temporal resolution of the EEG technique in a controlled experiment with industrial designers, architects, engineers and graphic designers performing a sequence of tasks. A generic design hypothesis was proposed by Goel and Pirolli (1989, 1992) regarding the study of design as a subject matter in its own right based. This attempt was augmented to a cognitively oriented generic design hypothesis (Visser, 2009). Several attempts have demonstrated similarities and differences across design and non-design disciplines (Vieira, 2018). With this study we aim to answer the research question: How far EEG can help distinguish design from problem solving?

The objectives of the study are to:

- investigate the use of the EEG technique to distinguish design from problem solving;
- correlate results of brain wave power and amplitude to Brodmann areas, function and connectivity with design cognition; and
- identify similarities and differences across various design backgrounds.

2. METHODS

We have adopted and replicated the tasks described in Alexiou and Zamenopoulos et al. (2009), augmenting their results with EEG high temporal resolution. We extend the experiment to a third task. The set of three tasks is preceded by a pre-task so that the participants can familiarize themselves with the physical interface. The three tasks are followed by a fourth task based on free-hand sketching. The replication of the experiment tasks of Alexiou and Zamenoupoulos et al. (2009) with EEG brain wave data is supported with the analysis of data from video and audio recording and observation for protocol and FBS ontology (Gero and McNeil, 1998) analysis, which will be reported elsewhere

A physical interface for individual task performance was built based on magnetic material for easy handling. The Mikado game was given to the participants to play in the breaks between tasks as they have to accurately pick each piece of the game this action helps them with the physical interface of the magnetic and movable pieces during the tasks. A pre-task was designed so that participants can familiarize themselves with the use of the headset, maneuvering the magnetic pieces and prevent him/her from getting fixated in task. 1. The block experiment consists of a sequence of 3 tasks: problem solving, basic design and open design, Table 1. For the present study we have matched tasks 1 and 2 with the problem solving and design tasks from Alexiou et al. (2009) as closely as possible in terms of difficulty, number of constraints, stimuli, number of instructions so that the cognitive effort to understand them is close. The purpose is to observe differences in participants' brain activation due to the nature of the tasks, Figure 1. Task 3 provides an enlargement of the problem and the solution space. The third task provides the opportunity of evaluating and reformulating the design solutions. In Task 4, free-hand sketching, the participants are asked to propose and represent an outline design for a future personal entertainment system.

The EEG activity is recorded using a portable 14-channel system Emotiv Epoc+. Electrodes are arranged according to the 10-20 I.S. The subjects performed the tasks on a physical magnetic board, with two video cameras for capturing the participant face and activity and an audio recorder.

Table 1. Description of the problem-solving, basic design and open design tasks.

Task 1 – Problem solving	Task 2 – Basic design	Task 3 – Open design
In Task 1 the design of a set of furniture is available and three conditions are given as requirements. The task consists of placing the magnetic pieces inside a given area of a room with a door, a window and a balcony.	In Task 2 the same design set of furniture is available and three requests are made. The basic design task consists of placing the furniture inside a given room area according to each participant notions of functional and comfortable using at least three pieces.	In Task 3 the same design available is complemented with a second board of movable pieces that comprise all the fixed elements of the previous tasks, namely, the walls, the door, the window and the balcony. The participant is told to arrange a space.

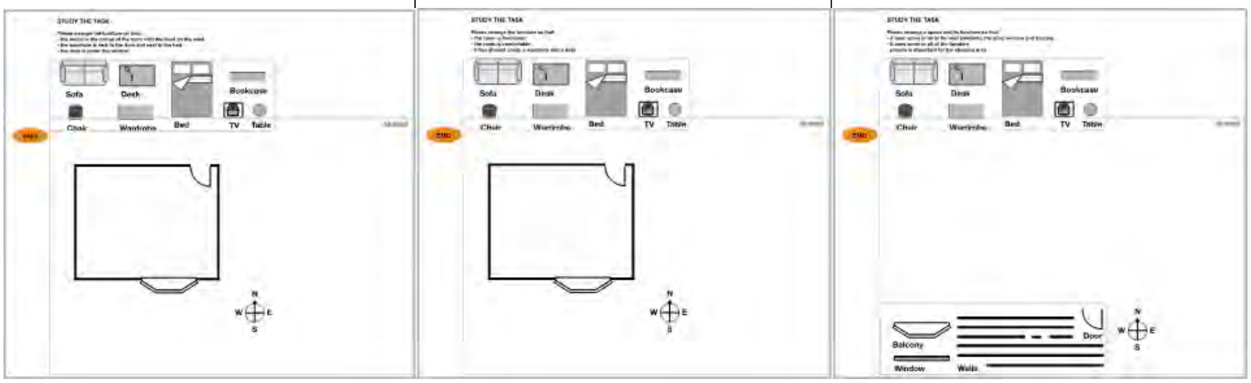

Figure 1. Depiction of the problem solving Task 1, basic design Task 2, and open design Task 3.

All the data captures were streaming in Panopto software (https://www.panopto.com/) that also allows for direct screen capture. One researcher is present in each experiment episode for recordings and instructing the participant. A period of 10 minutes for setting up and a few minutes for a short introduction are necessary for informing each participant, reading and signing of the consent agreement and discussing the experiment. The researcher positions the participant at the desk and checks metallic accessories for electromagnetic interference, Figure 2.

Figure 2. Emotiv Epoc+ electrodes arrangement (10-20 I.S.) and experiment setup using the headset.

The researcher sets the room temperature. The researcher asks each participant's attention for neck movements, blinking, muscle contractions as well, rotating the head, horizontal eye movements, pressing the lips and teeth, and silly faces in particular during the tasks, as these affect the signal capture. Electromagnetic interference of the room was checked for frequencies below 60Hz. The researcher follows a script to conduct the experiment so that each participant gets the same information and stimuli. Before each task, participants were asked to start by reading the text which took an average of 10s of reading period. Then the subjects performed the sequence of five tasks previously described with breaks in between where they play Mikado. The experiments took a total time between 34 to 76 minutes. The experiments with the Emotiv Epoc+ equipment took place between March and July of 2017 in a room with the necessary conditions for the experiment, such as natural lighting from above sufficient for performing experiments between 9:00 and 15:00 and no electromagnetic interference.

In this presentation we describe the analysis of 12 individuals. Results depicted are based on seven industrial designers aged 22-35 (M = 25.5, SD = 4.6), and five mechanical engineers, aged 22-28(M = 25.6, SD = 2.3). The sample included eight men (M = 24.8, SD = 2.2) and 4 women (M = 26, SD = 6.2), all right-handed. This study was approved by the local ethics committee of the University of Porto.

For the present analysis all the segments of the recorded data were used for averaging throughout the entire tasks, from beginning to end. In this research we adopt the blind source separation (BSS) technique based on canonical correlation analysis for the removal of muscle artifacts from EEG recordings (De Clercq et al., 2006; Vergult et al., 2007) adapted to remove the short EMG bursts due to articulation of spoken language, attenuating the muscle contamination on the EEG recordings (Vos et al., 2010).

The signals were recorded by the means of the portable 14-channel system Emotiv Epoc+. The fourteen electrodes were disposed according to 10-20 I.S, 256 Hz sampling rate, low cutoff 0.1 Hz, high cutoff 50 Hz. Data processing includes the removal of DC offset with the IIR procedure, and the previously mentioned blind source separation technique (BSS). Data analysis proceeds with total and band power values on individual and aggregate levels in MatLab and open source software.

3. EEG DATA ANALYSIS AND RESULTS

The analysis is based on the EEG data recorded and processed for each of the 12 experiments and the 14 electrodes used for averaging throughout the entire tasks. As the focus of the present study is to know how far designing can be distinguished from problem solving we take the problem solving task 1 as the reference period for the task-related power (TRP) calculations. By doing this, the negative values indicate a decrease of task-related power from the reference (problem solving Task 1) to the activation period, while positive values express a power increase (Pfurtscheller and Lopes da Silva, 1999). Results of the total TRP across the twelve participants, are depicted in Figure 3.

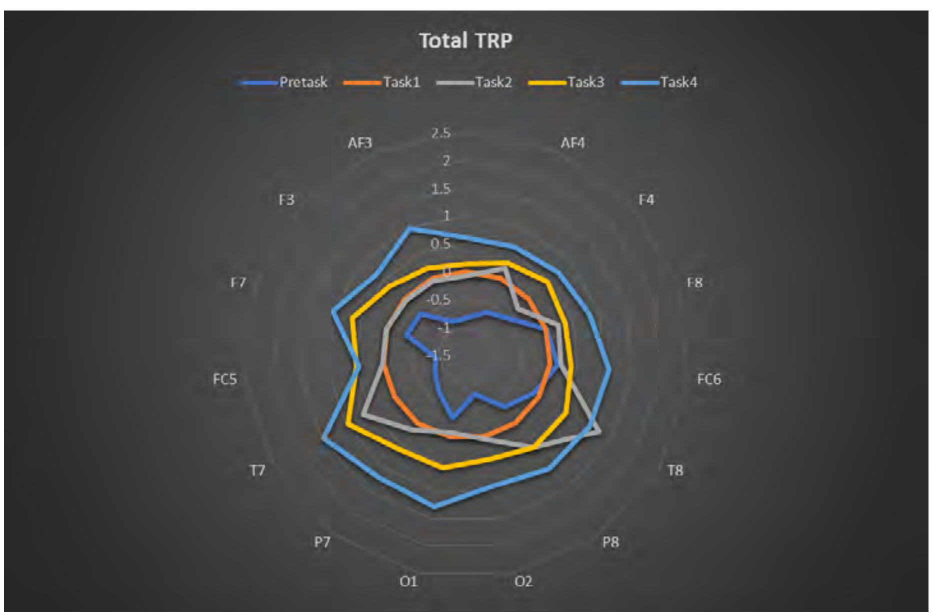

Figure 3. Task related power (TRP) for the 14 electrodes by taking problem solving Task 1 as the reference period across the 12 participants and the five tasks.

Once the problem solving Task 1 is subtracted from itself to produce the reference, it shows up as a circle. Higher activation or deactivation of the electrodes/regions per task is shown within or beyond the circle border. The plot simulates the two hemispheres by distributing the electrodes symmetrically. Total TRP scores per electrode can be considered by comparing with the vertical scale and across the different tasks. The analysis of task-related power (TRP) allowed a preliminary comparison on differences between industrial designers and mechanical engineers based on TRP. Results between the two sets of tasks for the industrial designers and mechanical engineers are depicted in Figure 4.

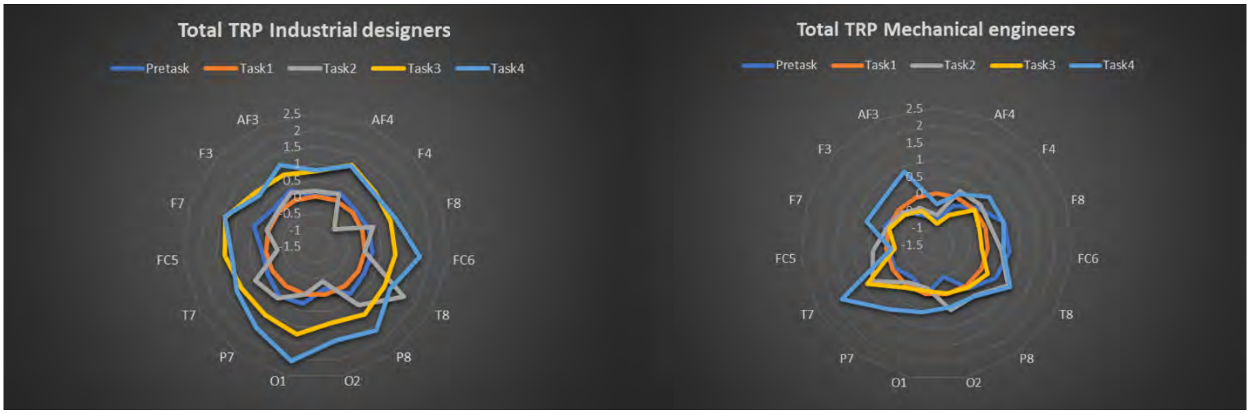

Figure 4. Task-related power (TRP) for the four tasks for the industrial designers and mechanical engineers

To compare the TRP of industrial designers and mechanical engineers, we performed a preliminary analysis by running a 2x4x2x7 mixed repeated-measurement ANOVA, with the between-subjects factor background and the within-subject factors task, hemisphere and electrode. From the analysis of the 12 participants (7 industrial designers and 5 mechanical engineers) we found a marginally significant main effect of task, $F_{GG}(1.67, 50.57)=2.24$, $p=.14$, $\eta^2_{partial}=.18$ (corrected for Greenhouse-Geisser estimates of sphericity, $\varepsilon = .56$). None of the other factors showed a significant or close to significant main effect. Moreover, the ANOVA revealed no significant interactions between factors with the exception of a significant three-way interaction effect between task, hemisphere and electrode, $F(18, .47) = 1.86$, $p < .02$, $\eta^2_{partial} = .16$. As the preliminary analysis is based on a very small sample ($N = 12$), some of the differences are likely to become significant once the sample includes data from more participants. Nevertheless, pairwise comparisons can serve as preliminary indicators of significant ($p \leq .05$) and close to significant ($p \leq .15$) differences between industrial designers and engineers when compared on the 7 electrodes per hemisphere and task. Based on the current data, the following comparisons were marginally significant or significant: for the pre-task*,* electrode AF3 ($p = .06$); for Task *2*, electrodes T7 ($p = .06$), FC5 ($p = .07$) in the left hemisphere; for Task *3*, electrodes AF4 ($p = .14$), P8 ($p = .13$) in the right hemisphere; for *task 4*, electrodes P8($p = .04$), O2($p = .14$) in the right hemisphere and electrodes O1($p = .06$), FC5 ($p = .10$) in the left hemisphere. There was no adjustment for multiple comparisons. Some deactivations per group will be analyzed and interpreted in further studies. Preliminary indicators of significant and close to significant differences of some electrodes/regions and hemisphere across tasks are shown in Figure 5.

Figure 5. Preliminary indicators of significant and close to significant differences of some electrodes/regions and hemisphere across tasks.

These preliminary results show significant and close to significant difference between industrial designers and mechanical engineers, in some electrodes which approximate localization of brain activation is associated to Brodmann areas, namely: for the pre-task*,* electrode BA 9 (AF3); for Task *2*, electrodes BA 42 (T7), Broca's area (FC5) in the left hemisphere; for *task 3*, electrodes BA 9 (AF4), BA 38 (P8) in the right hemisphere; for *task 4*, electrodes BA 38 (P8), BA 18(O2) in the right hemisphere and electrodes BA 18(O1) and Broca's area (FC5) in the left hemisphere. There was no adjustment for multiple comparisons.

4. DISCUSSION AND CONCLUSION

Preliminary results from this study demonstrate that it is possible to address the three objectives:

- investigate the use of the EEG technique to distinguish design from problem solving;
- correlate results of brain wave power and amplitude to Brodmann areas, function and connectivity with design cognition; and
- identify similarities and differences across various design backgrounds.

On a qualitative level the present study shows evidence of a distinct characteristic of increased task-related power activation of design tasks from the reference problem solving task across industrial designers and mechanical engineers. On a statistical level, more data collection and analysis will test the validity of the claim as some significant and close to significant ANOVA results on some electrodes/regions indicate a possible effect. Further studies will focus on band waves filtering and temporal analysis of the EEG data.

Once statistically robust cohorts have been collected a more detailed analysis of the data will address temporal questions of changes in neurocognition over time while designing. As part of the larger project think-aloud protocol have been collected while measuring EEG responses. The removal of effects due to speech will allow the temporal matching of design cognition with neurophysiology, opening up a new research direction for neurocognitive research in design studies.

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