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ANALYSIS OF DESIGN ACTIVITIES USING EEG SIGNALS

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ABSTRACT

It plays a significant role in developing of design theory and methodology to understand designer's thinking and cognitive process during design activities. The most dominant method to conduct this kind of study is protocol analysis. However, this method is prone to subjective factors. Therefore, other approaches are emerging, which can measure the brain activities directly. With the advances in technologies, brain scanner and brain recorder systems such as EEG, fMRI, PET have become more affordable. In the present research, we used EEG to record designer's brain electrical signals when s/he was working on a design task. Six channels of the EEG signals were recorded, including Fp1, Fp2, Fz, Cz, Pz, Oz, based on which the power spectral density for each EEG band (delta, theta, alpha and beta) was calculated. The results showed that, for the given design problem, the subject spent more effort in visual thinking during the solution generation than that in solution evaluation. The preliminary success in identifying regularity underlying a single designer's design process through EEG signals lays a foundation for further investigation of designers' general mental efforts during the conceptual design process.

1. INTRODUCTION

The purpose of this paper is to introduce an EEG based approach to analyzing design activities. This research effort is motivated by two observations that we have made about design and design research.

Firstly, it is important to quantify the designer's cognitive processes in order to develop an effective, structured and logical design methodology that can accommodate the flexibility and freedom in the creative design process. Over the last few decades, various design methodologies have been proposed to assist designers in generating quality designs in an effective manner [1-5]. There is no doubt that the existing methodologies have been greatly influencing the industrial product design process. However, a big challenge is still faced in applying those design methodologies, which lies in two contrasting facts. On the one hand, design is a creative act, which is rooted in the *flexibility* and *freedom* for exploring various avenues to achieve design goals [6-9]. On the other hand, any design methodology implies a set of well *structured logical* steps for solving a design problem. This contradiction between flexibility and structure and between freedom and logic is made even more complicated by an intrinsic nature of design: design solutions must pass an evaluation defined by design knowledge that is interdependently and recursively determined by the design solutions to be evaluated [10]. Naturally, the in-depth investigation of designer's cognitive process is a necessary condition for creating a design methodology that is both structured for implementation and flexible for designer's creativity.

Secondly, protocol analysis is dominant in the current experimental study of design activities [11-18]. Protocol analysis is a method of analyzing subjects' behaviors based on dialogue, thinking-aloud, video recording, sketches, notes, etc [19]. The major problem is that the method is not the direct measurement of brain activities; hence, the results from the analysis are not easy to be validated. The direct measurement of physiological brain parameters can validate or correct the observations coming from verbal protocol analysis. The first known study in design using brain signal data was conducted by Göker in 1997 [20]. Göker focused on the effect of designer's experience on approach to design solution. The most recent research conducted by Alexiou et al. [21] uses magnetic resonance imaging (fMRI) to show the activation of brain areas when subjects do design task and when subjects do problem-solving task. Alexiou et al. claimed that active brain areas are distinctly different between design task and problem-solving task.

In this paper, we propose an EEG based method to analyze designer's cognitive operations during conceptual design process. The rest of this paper is organized as follows: Section 2 introduces an EEG based approach; an experiment is given in

Section 3 to validate the experiment protocol. Discussion is given in Section 4 and finally conclusions and future works are discussed in Section 5.

2. EEG BASED APPROACH

2.1. EEG and Brain Functions

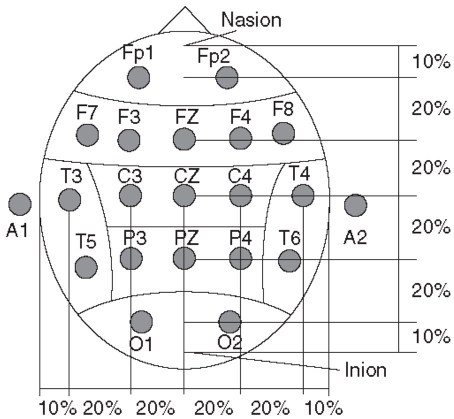


FIGURE 1. THE 10-20 INTERNATIONAL SYSTEM OF ELECTRODE PLACEMENT [22]

The brain continuously generates electrical signals that can be detected and recorded from the electrodes attached to the scalp [23]. The placement of the electrodes usually follows the standard 10-20 International System of Electrode Placement as shown in Figure 1 [22], which specifies the positions where the electrodes should be placed. The position is denoted by the first letter of the brain area and the number stating the site and the position within the area. The odd and even numbers indicate the left and right sides of the brain, respectively.

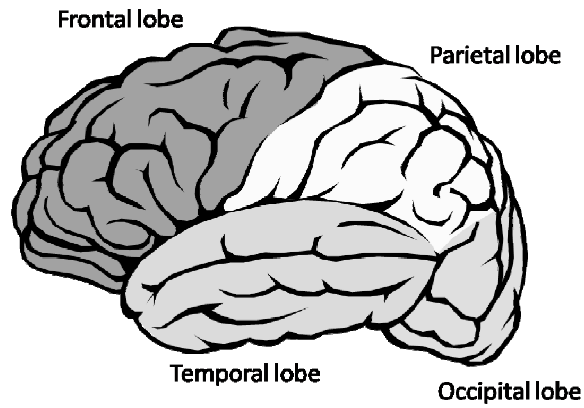


FIGURE 2. AREAS OF THE BRAIN

The recordings obtained from the electrodes are called electroencephalogram (EEG) [22]. EEG signals can be recorded from four different regions of a brain: frontal lobe, parietal lobe, temporal lobe, and occipital lobe (Figure 2). Each lobe is responsible for specific brain functions, as is shown in Table 1 [23, 24]. EEG signals are categorized into four bands in terms of their frequencies: delta (1-4Hz), theta (4-8Hz), alpha (8-13Hz) and beta (13-30Hz), each of which has different functions [22]. In clinical studies, these frequency bands are found to be associated with certain mental states. The mapping between the bands and their associated mental states is given in Table 2 [23].

TABLE 1. BRAIN REGIONS AND THEIR FUNCTIONS [23, 24]

Brain region	Functions
Frontal lobe	Planning, judgment, making decision, concentration, emotions, motor
Parietal lobe	Verbal understanding, texture and shape interpretation
Temporal lobe	Auditory processing, auditory memory
Occipital lobe	Visual processing, visual experiences, eye focusing

TABLE 2. TYPES OF BRAIN WAVES [23]

Brain waves	Characteristics
Delta wave (1-4Hz)	Dominant when a person is sleeping
Theta wave (4-8Hz)	Dominant in temporal and occipital lobe during relaxed, awaking state.
Alpha wave (8-13Hz)	Dominant in occipital and parietal lobe during relaxed, awaking state with eye closed.
Beta wave (13-30Hz)	Dominant in frontal region during mental activity

2.2. Experiment Setting

In the experiment, the subject uses an electronic tablet as a means to express his or her solution. Instead of sketching or writing on a piece of paper, subject draws and writes on the tablet. In this way, all design data can be recorded by a screen recording software. The subject's brain signals are recorded by an EEG device. Three cameras are set to capture subject's facial expression, hand and body movements. Data obtained from the cameras will complement the data obtained from the screen recorder and EEG system.

2.3. Experiment Procedure

Before the experiment starts, the subject is asked to read and sign a consent form. The subject is also informed of the experiment procedure in details. Only after the subject signs the consent form, can the experimenter proceed to conduct the experiment.

During the first five minutes of the experiment, the subject is asked to relax. The purpose of these five minutes is to measure the resting state which can be served as the baseline to evaluate the cognitive state during design activities. This stage of the experiment is referred to as the resting phase. After the resting phase, the subject is given the design problem description. While designing, the subject is not interrupted; however s/he can ask questions to clarify the design requirements. The subject informs the experimenter when the design is completed. Another five minute resting phase is taken before the experiment actually ends.

2.4. Data Processing

Before EEG analysis, the raw EEG data has to be processed because it is usually contaminated with artifacts. Artifacts are signals that do not originate from mental activities. There are two major types of artifacts: artifacts from physiological sources and artifacts from non-physiological sources [25]. Physiological artifacts are generated from the subject's body but are not related to the concerned mental activities such as skin perspiration and involuntary eye and muscle movement. Non-physiological artifacts are generated from the surrounding environment such as electrical interference caused by electrical equipment or cable movements of the EEG recording device. There is a variety of techniques for artifact removal including amplitude threshold, min-max threshold, spectral distribution, standard deviation, and low activity [26].

2.5. Data Analysis

Based on our observation on the recorded videos, we categorize design activities into four operations: problem analysis, solution evaluation, solution generation, and solution expression. Problem analysis refers to problem understanding and problem formulation. Solution evaluation refers to any activities that may involve comparing, calculating, and analyzing a design solution. Solution generation is defined as the mental activities that will lead to solution expression. Solution expression refers to activities that express the subject's thinking such as copying and moving objects.

The relationship between the four operations of design activities are depicted in Figure 3. The subject starts the design by understanding the requirements and by identifying the problem (problem analysis), followed by the generation of solutions (solution generation). The solutions can be evaluated (solution evaluation) and refined before being expressed in drawing or writing (solution expression). After expressing the solution, the subject may evaluate the current design state; may generate new solutions; may analyze the design problem or may refine the requirements. The process continues until the solution satisfactorily meets all the requirements identified in the design problem.

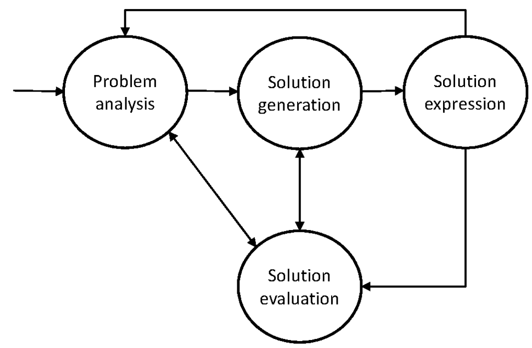


FIGURE 3. RELATIONSHIPS BETWEEN FOUR TYPES OF DESIGN ACTIVITIES

Based on these four types of operations, the screen recorded data, which is a record of subject's "sketching" and "sketches", is segmented. The EEG data, in turn, is also segmented based on the screen segments. The EEG analysis is conducted based on these EEG segments. Different EEG analysis methods can be chosen to fit the objectives of the interested study.

3. EXPERIMENT

Following the framework introduced in Section 2, we conducted an experiment in which the subject was given a design problem to solve while his or her brain signals were recorded. The purpose of this experiment is to validate and improve the experiment protocol in using EEG for analyzing design activities. Since design is a recursive process in which design problem will be redefined every time a partial solution is generated [27], a complete design process is indeed comprised of a series of different design problems. Therefore, although the subject works on only one design problem, s/he indeed solves many small design problems, each of which can be seen as one trial from experiment design point of view.

By doing so, the data obtained provides a large pool of samples for a statistically meaningful analysis of an individual designer's activities. This is shown in Table 3. The developed experiment protocol can then be applied to analyze other designers. This approach is necessary for the application of a complex device like EEG to a sophisticated activity like design.

3.1. Design Problem

The design task is to fit seven beds and a desk into a cottage bedroom. The room accommodates seven children. The size of the bed, the desk and the bedroom are 100×200, 70×130 and 380×480 (in centimeter), respectively. Because the children have different needs, the arrangement of the beds should satisfy the needs of each child. Figure 4 illustrates the design problem. There is no time limit in solving the problem.

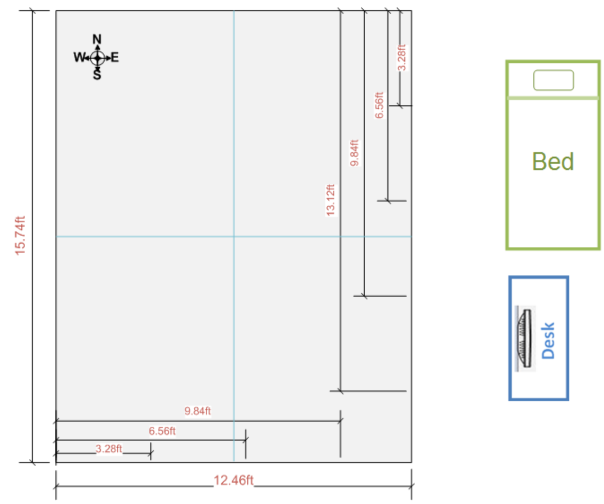


FIGURE 4. DESIGN TASK

3.2. Data Collection

The experiment was conducted with one subject. The subject is an engineering graduate student. The experiment was arranged in the morning between 10AM to 12PM. The data recorded included EEG data (Figure 5), screen captured data (Figure 6), and video data (Figure 7). The EEG data were recorded at six channels - Fp1, Fp2, Fz, Cz, Pz, and Oz (for concrete locations, please refer to Figure 1).

3.3. Data Processing and Analysis

Firstly, the screen captured data was segmented. An example of the segmentation is given in Table 3; each activity in the video was coded according to the assumption of the relationships of four types of design operations as mentioned in Section 2 (Figure 3).

Problem analysis was assigned to segments that showed subject's action of reading the requirement. During solution generation, solution evaluation might also occur but we considered the whole process as solution generation. Solution expression was assigned to segments that showed subject's moving and copying the beds/desks. Solution generation was assigned to segments preceding solution expression. Actions that did not clearly show subject's intention or were not related to design activity were labeled with letter O.

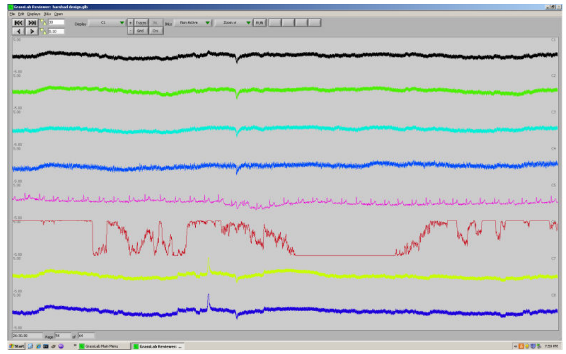


FIGURE 5. EEG DATA

FIGURE 6. SCREEN CAPTURING DATA

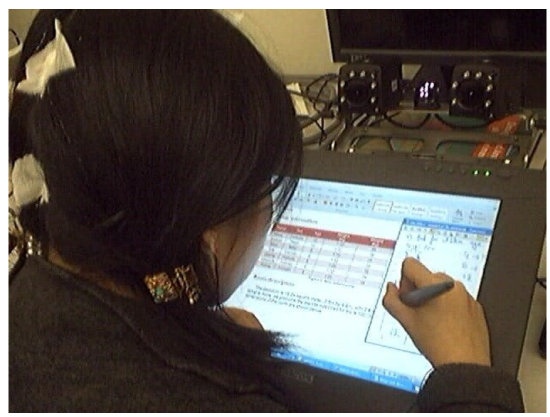


FIGURE 7. VIDEO DATA

Secondly, the raw EEG data was segmented based on the video segments. A band-pass filter with high edge frequency at 30Hz and low edge frequency at 1Hz was applied to the raw data. The raw and filtered EEG data are shown in Figure 8 and Figure 9, respectively. We also manually inspected EEG data to remove bad EEG segments. Originally, we had 287 segments.

TABLE 3. EEG SEGMENTS

Segment No.	Start Time	End Time	Duration	Description of activity	Label	
1	0:00:29	0:02:24	0:01:55	Check the software	O	
2	0:02:24	0:07:22	0:04:58	Relax	O	
3	0:07:22	0:09:44	0:02:22	Read problem description	PA	
4	0:09:44	0:10:09	0:00:25	Scroll up and down	O	
5	0:10:09	0:10:21	0:00:12	Move bed 1	SG	CE
6	0:10:21	0:10:28	0:00:07	Rotate bed 1	SG	CE
7	0:10:28	0:10:34	0:00:06	Move bed 1	CE	
8	0:10:34	0:10:35	0:00:01	Brief idle	SE	
9	0:10:35	0:10:55	0:00:20	Read problem description	PA	SG
10	0:10:55	0:11:03	0:00:08	Make copy of bed 1	CE	
...	...	...	...	...	...	
283	0:30:30	0:30:36	0:00:06	Resize bed 2	CE	
284	0:30:36	0:30:40	0:00:04	Evaluate bed 8, complete the design	SE	
…	…	…	…	…		

- ✓ Total segments: 287
- ✓ Valid segments: 260

- O: activities that are not related to design
- PA: problem analysis
- CE: solution expression
- SE: solution evaluation
- SG: solution generation

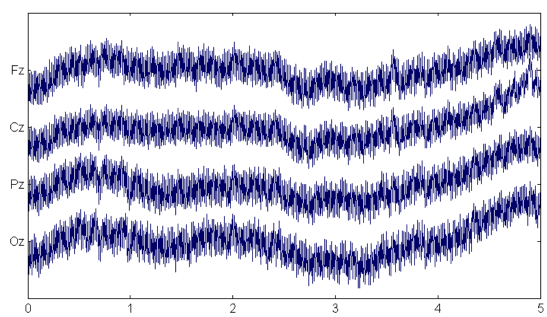


FIGURE 8. RAW EEG DATA

After pre-processing EEG data, we removed 12 segments associated with badly distorted EEG signals. Among the remaining segments, we identified 260 segments that were of interest. For example, segment number one in Table 3 was removed since it was not of interest.

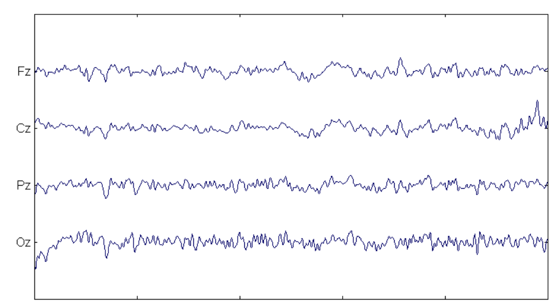
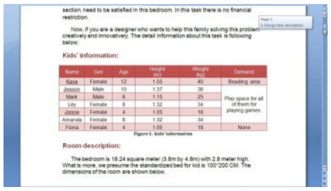
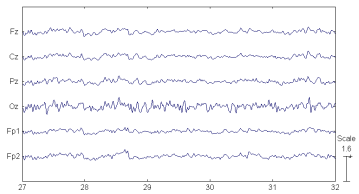
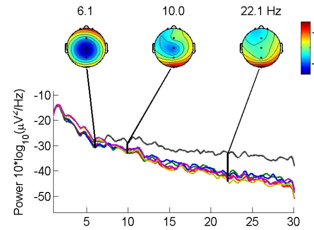
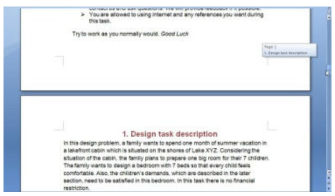
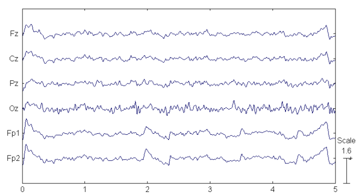
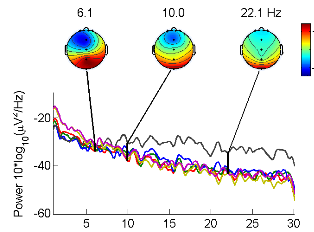
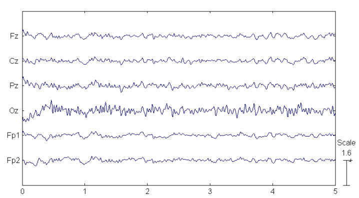
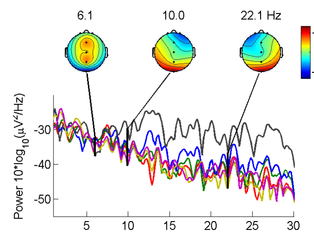


FIGURE 9. FILTERED EEG DATA

TABLE 4. VIDEO DATA, EEG DATA AND POWER SPECTRA FOR EACH SEGMENT

Segment No.	Screen recorded data	Filtered EEG data	Power spectra
3			
4			
5			

For each valid EEG segment, power spectra were computed using EEGLab [28]. Three examples are given in Table 4. The power of resting phase was subtracted from that of each design-related EEG segment to show the change in power during design activities relative to the resting state.

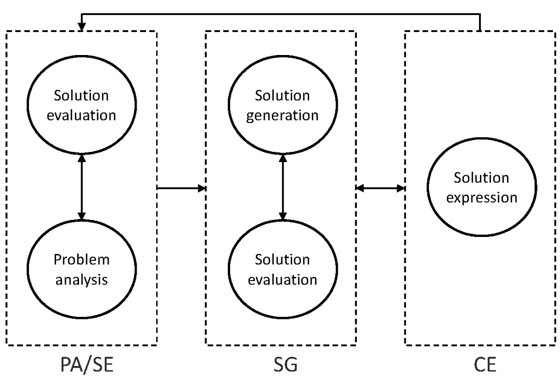


FIGURE 10. COMPONENTS OF A SEGMENT SET (SG: SOLUTION GENERATION, SE: SOLUTION EVALUATION, CE: SOLUTION EXPRESSION)

Subsequently, the segments were grouped into sets of sub-design problems, each of which was comprised of a sequence of design activities starting from problem analysis/solution evaluation to solution generation and ending with solution expression. The difficulty that we encountered was that problem analysis, defined when the subject is reading requirement, is not always present in the video. Therefore, we substituted problem analysis with solution evaluation taken from solution generation. The components of a set are illustrated in Figure 10. An example of a set of EEG segments is illustrated in Table 5.

TABLE 5. AN EXAMPLE OF EEG SEGMENT SETS (PA: PROBLEM ANALYSIS, SG: SOLUTION GENERATION, CE: SOLUTION EXPRESSION)

Set No.	Segment No.	Label	
1	3 5	PA SG	CE
2	6 7	SG CE	CE
3	8 9 10 20 21	SE PA CE CE CE	SG
4	22 23	SG CE	
…	…	…	

TABLE 6. POWER VALUE, WEIGHT VALUE FOR EACH SEGMENT, AVERAGE AND STANDARD DEVIATION FOR EACH DESIGN ACTIVITY

Set No.	Seg No.	Label	Fz			Cz			Pz			Oz			Fp1			Fp2		
			Theta	Alpha	Beta	Theta	Alpha	Beta	Theta	Alpha	Beta	Theta	Alpha	Beta	Theta	Alpha	Beta	Theta	Alpha	Beta
1	3	PA	-4.4E-03	-1.7E-03	3.0E-03	-8.5E-03	-5.1E-03	-6.3E-04	-5.8E-03	-8.9E-03	-8.2E-04	7.8E-03	1.2E-02	1.5E-02	1.9E-02	4.4E-03	-4.1E-04	1.9E-02	4.8E-03	-4.1E-04
	5	SG	-2.4E-02	-9.2E-03	-4.7E-03	-2.6E-02	-1.1E-02	-3.8E-03	-2.6E-02	-1.4E-02	1.8E-03	-1.7E-02	1.0E-02	4.9E-02	-1.9E-02	-5.1E-03	-2.4E-03	-2.3E-02	-6.8E-03	-2.8E-03
		CE	-2.4E-02	-9.2E-03	-4.7E-03	-2.6E-02	-1.1E-02	-3.8E-03	-2.6E-02	-1.4E-02	1.8E-03	-1.7E-02	1.0E-02	4.9E-02	-1.9E-02	-5.1E-03	-2.4E-03	-2.3E-02	-6.8E-03	-2.8E-03
2	6	SE	-3.3E-02	-1.2E-02	-7.6E-03	-3.5E-02	-1.5E-02	-7.2E-03	-3.3E-02	-2.0E-02	-7.2E-03	3.7E-03	7.3E-02	9.2E-02	-2.5E-02	-7.3E-03	-4.7E-03	-3.0E-02	-9.8E-03	-5.6E-03
		SG	-3.3E-02	-1.2E-02	-7.6E-03	-3.5E-02	-1.5E-02	-7.2E-03	-3.3E-02	-2.0E-02	-7.2E-03	3.7E-03	7.3E-02	9.2E-02	-2.5E-02	-7.3E-03	-4.7E-03	-3.0E-02	-9.8E-03	-5.6E-03
	7	CE	-3.1E-02	-1.3E-02	-7.4E-03	-3.3E-02	-1.4E-02	-7.0E-03	-3.1E-02	-2.0E-02	-6.2E-03	-8.3E-03	3.2E-02	4.7E-02	-2.4E-02	-8.0E-03	-4.7E-03	-2.9E-02	-1.0E-02	-5.8E-03
3	8,9	SE/PA	-2.9E-02	-9.0E-03	-5.0E-03	-3.0E-02	-9.3E-03	-3.1E-03	-2.4E-02	-9.4E-03	-2.4E-03	1.4E-03	2.1E-02	4.2E-02	-2.0E-02	-4.9E-03	-3.3E-03	-2.4E-02	-7.7E-03	-4.0E-03
	9	SG	-2.7E-02	-6.9E-03	-4.5E-03	-2.8E-02	-8.8E-03	-2.9E-03	-2.4E-02	-1.4E-02	1.1E-05	1.0E-02	2.0E-02	6.8E-02	-1.9E-02	-2.9E-03	-1.9E-03	-2.3E-02	-5.1E-03	-2.2E-03
	10,20.21	CE	-2.7E-03	2.0E-03	1.2E-02	-2.2E-02	-7.4E-03	4.4E-04	-2.9E-02	-1.6E-02	-5.4E-03	-2.3E-02	-5.3E-03	2.0E-03	-1.5E-02	2.0E-03	9.1E-03	-1.7E-02	8.9E-04	7.3E-03
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

Set No.	Seg No.	Label	Fz			Cz			Pz			Oz			Fp1			Fp2		
			Theta	Alpha	Beta	Theta	Alpha	Beta	Theta	Alpha	Beta	Theta	Alpha	Beta	Theta	Alpha	Beta	Theta	Alpha	Beta
1	3	PA	3	3	3	3	3	3	3	3	1	3	3	1	2	3	3	3	3	3
	5	SG	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.5	1.5	1.5	2.5	2	1.5	1.5	1.5	1.5	1.5
		CE	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.5	1.5	1.5	2.5	2	1.5	1.5	1.5	1.5	1.5
2	6	SE	1.5	2.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.5	2.5	2.5	1.5	2.5	2	1.5	2.5	2.5
		SG	1.5	2.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.5	2.5	2.5	1.5	2.5	2	1.5	2.5	2.5
	7	CE	3	1	3	3	3	3	3	3	3	1	1	1	3	1	2	3	1	1
3	8,9	SE/PA	1	1	1	1	1	1	2.5	3	2	2	3	2	1	1	1	1	1	1
	9	SG	2	2	2	2	2	2	2.5	2	3	3	2	3	2	2	2	2	2	2
	10,20.21	CE	3	3	3	3	3	3	1	1	1	1	1	1	3	3	3	3	3	3
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

	Label	Fz			Cz			Pz			Oz			Fp1			Fp2		
		Theta	Alpha	Beta	Theta	Alpha	Beta	Theta	Alpha	Beta	Theta	Alpha	Beta	Theta	Alpha	Beta	Theta	Alpha	Beta
Average	PA/SE	2.15	2.01	2.09	2.16	1.99	2.15	2.01	2.12	2.10	2.07	2.10	2.10	2.16	2.15	2.16	2.19	2.24	2.16
	SG	2.04	2.07	1.93	1.95	1.95	2.01	1.95	2.07	2.11	2.04	2.02	2.12	2.07	1.99	2.04	2.06	2.00	2.04
	CE	1.82	1.92	1.98	1.89	2.07	1.85	2.04	1.82	1.79	1.89	1.88	1.78	1.76	1.87	1.79	1.75	1.76	1.79
Standard deviation	PA/SE	0.64	0.64	0.60	0.61	0.65	0.62	0.66	0.65	0.63	0.61	0.68	0.58	0.64	0.62	0.63	0.66	0.62	0.68
	SG	0.55	0.60	0.63	0.61	0.59	0.59	0.60	0.61	0.59	0.65	0.56	0.62	0.58	0.60	0.62	0.57	0.63	0.57
	CE	0.95	0.94	0.94	0.94	0.94	0.94	0.93	0.90	0.92	0.92	0.93	0.93	0.91	0.94	0.90	0.90	0.88	0.90

Each component in a set was assigned a weight value ranging from one to three. Component with the largest spectral value has weight 3 and the smallest weight 1. Those having the equal value have equal weight. The average was taken for all the components of the same type across the sets. The goal is to find the brain power distributed relatively among problem analysis/solution evaluation, solution generation and solution expression in a set.

Examples of the calculation are given in Table 6. Segment six is not labelled as SE (solution evaluation) in Table 5 when coding but labelled as SE in Table 6 when computing the average. The reason for this inconsistency is, as mentioned previously, problem analysis is not always present. Therefore, in order to have value solution evaluation, solution evaluation was taken from solution generation (solution generation may include solution evaluation as depicted in Figure 10).

3.4. Results

As mentioned in Section 2, each brain area is associated with different functions. In this experiment, we recorded the brain signals from frontal lobes, parietal lobe and occipital lobe. Table 7 shows the electrode position and the corresponding brain region.

TABLE 7. ELECTRODE POSITION AND CORRESPONDING BRAIN LOBES

Electrode Position	Brain region
Fp1, Fp2, Fz	Frontal lobe
Cz	Vertex
Pz	Parietal lobe
Oz	Occipital lobe

It can be observed from Table 6 that the beta power is high at solution evaluation and low at solution expression in channels Fp1, Fp2. Channels Fp1 and Fp2 are located over the region of the brain which is responsible for memory retrieval, decision making, planning, response evaluation, and reflection [24]. The result confirms that the subject spent most of the mental efforts in reflection and judging during problem analysis and solution evaluation (Figure 11).

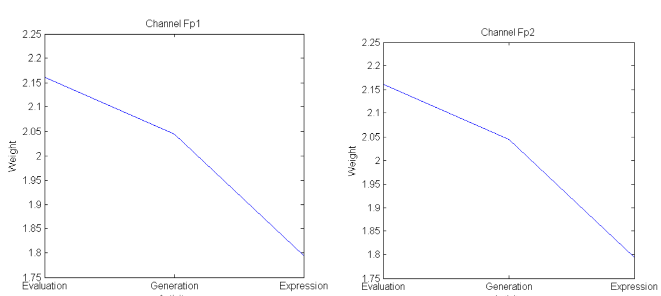


FIGURE 11. BETA BAND AT FP1 AND FP2

In addition, research has shown that theta band in Fz increases in magnitude with increased memory load and attention [29]. In Fz, we also observed a very high theta power at SE and low power at solution expression. These results show that the subject spent more mental efforts in problem analysis/solution evaluation than those in solution generation and solution expression (Figure 12).

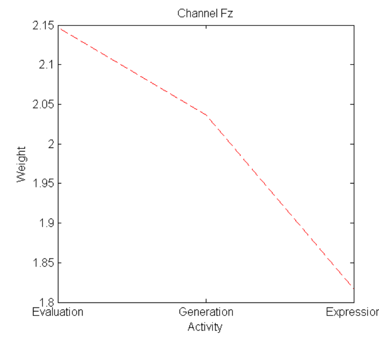


FIGURE 12. THETA BAND AT FZ

In Oz, we found high alpha power at solution evaluation but low at solution expression. This suggests that the subject spent more efforts in visual thinking [30] during solution generation than those during problem analysis/solution evaluation (Figure 13). It confirms the importance of visual design thinking in the solution generation process [31].

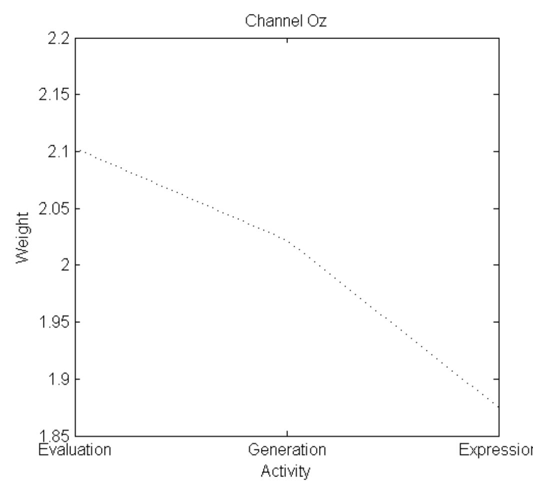


FIGURE 13. BETA BAND AT OZ

4. DISCUSSIONS

The results obtained from EEG data show the feasibility of using EEG as a complementary method to protocol analysis in understanding design activities.

However, during the analysis, we found that it was unclear when solution generation had happened and whether solution evaluation was occurring in the same time. For instance, in

Table 3, segment number five showed that the subject was moving a bed and segment number six showed that the subject was rotating the bed. The idea of moving and rotating (solution generation) could have been generated before the actions (moving and rotating) happened. Moving and rotating are just two actions without new ideas being generated. On the other hand, it was also possible that the idea of moving was generated first before the subject made the movement. During or after the moving process, the idea of rotating the bed occurred to the subject.

Furthermore, the expressed solution can come from the solution generating process with or without going through the evaluation process. Solution evaluation and generation may also occur recursively. Similarly, solution evaluation can occur during problem analysis. In this study, we assumed that solution evaluation is always present in problem analysis and solution generation with the equal brain effort.

The assumptions above may result in inaccuracy in our final results.

5. CONCLUSIONS AND FUTURE WORKS

In this paper, we proposed an approach to analyzing design activities using EEG data. We conducted an experiment to show the feasibility of using EEG data as an objective measurement of designer's cognitive states. Although only one subject was studied in this experiment, there was a large number of sub design problems naturally included in the design process. This fact makes this experiment equivalent of the one in which the subject conducted many trials in solving different design problems.

Our analysis showed that more efforts in prefrontal lobe, which is responsible for planning, judgment, reasoning and concentration, in solution evaluation than in other activities. In addition, the analysis also showed high visual thinking effort in solution generation compared to solution evaluation.

In the future, we will conduct experiment to find the EEG pattern for evaluating task so that we can identify or separate solution evaluation from other activities in design. We will adopt more advanced techniques for EEG artifact removal and conduct more sophisticated EEG analysis. The experiment will also be conducted with more subjects to identify generic nature underlying design activities.

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