EEG Patterns Analysis in the Process of Recovery from Interruptions

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Abstract This paper reports the results of the experiment addressing the recovery from interruption phenomenon in terms of brain activity patterns. The aim of the experiment was to find out whether it is possible to find any significant differences in brain activity between subjects performing the task in the recovery period better or worse than the control group. The main outcome from the experiment was that the brain activity of the subjects who performed better than the control group did not change significantly during back to task period compared to interruption period. On the contrary, for subjects whose performance was worse than in the control group, the significant changes in signal power in some frequency bands were found.

Keywords EEG pattern analysis · Brain activity patterns · Interruptions · Recovery from interruption · Human–computer interaction · HCI

1 Introduction

Nowadays, any human activity is performed in a very noisy environment. Digital and traditional media continuously deliver new information and distracting stimuli. As a result, it is very difficult to focus on a primary task, which is repeatedly interrupted by incoming messages, calls, advertisements, etc. Since in our times it is impossible to avoid interruptions, the main question posed in this field is how to continue a main task effectively after the interruption has been finished. This question has been addressed in earlier research from many different points of view. For example, in the field of human–computer interaction (HCI) usually the minimal negative impact of

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internal messages on demanding tasks is looked for [1]. On the other hand, in multitasking environments, the analysis is focused on finding the effective mechanisms for switching a user attention between tasks [2]. Yet, another research regards the relationship between the time of interruption and the efficiency of returning to the main task [3]. Of course also the influence of the type of interruption and type of task performed before the interruption on the successful recovery is analyzed [4].

The research carried out in the field has erupted in recent years due to the development of electronic systems enabling the direct analysis of the impact of interruptions on the decision process [5], and also enabling the simultaneous analysis of many aspects of interruptions, like timing, interruptions frequency, ability to block interruptions, the relevancy to main editorial content, etc. Along with developing the interactive media, new tools and environments for conducting cognitive research aimed at attracting user attention or influencing his current cognitive processes have also evolved [6].

Interruption is defined as "an externally generated randomly occurring, discrete event that breaks continuity of cognitive focus on a primary task" [7]. Other authors define interruption as an "unanticipated issue rising up from the environment while a main action is being performed" [8]. As a result of an unpredictable and uncontrollable nature of interruptions, the stress level of a task performer increases, which can have a negative effect on performance after interruption [9]. However, the stress level induced by an interruption is not constant—it differs significantly depending on many factors. Xia and Sudharshan analyzed the influence of interruptions on natural cognitive flow in relation to online customer decision processes for both abstract and concrete goals [5]. For customers who had to deal with concrete goals, a much higher level of frustration was detected.

Not only the users' stress level but also the quality of performance after interruption depends on external factors. However, while the stress is almost always present when the interruption occurs, the performance after interruption can be not only worse, but also the same or sometimes even better. An example of research with negative outcome can be the research conducted by Edwards and Gronlund [10]. They analyzed the similarity between interruption and primary task along with memory representation of primary task and found that when interruptions were related to the primary content, memory and performance were negatively affected.

Distraction and conflict theory also discuss the relationship between performance of primary task and disruptions [11]. Results of experiments, conducted by Baron, revealed that while disruptions affect the performance of complex task, they have not any direct effect when simple tasks are performed. However, even with simple tasks psychological negative effects of interruptions are observed [12].

Usually, the performance deteriorates when interruption appears [9], but in some research the opposite phenomenon is reported. For example, Speier in 1996 conducted a study aimed at analyzing the influence of different cognitive and social characteristics such as frequency, duration, content, complexity, timing (cognitive characteristics), and form of interruption techniques used for interruption generation and social expectations (social characteristics) [13]. The author showed that differences in characteristics of interruptions, types of goals, and individual differences of customers play important role in the performance after interruption. He proved also that when interruptions are used properly, they can be an effective technique for enhancing the quality of this performance, for example by attracting customer attention. Also most computer system users can handle interruptions effectively. They have the ability to switch attention between tasks and focus on the primary task immediately after interruption [14]. “Zeigarnik Effect” shows that details of interrupted tasks can be recalled even better than those of uninterrupted tasks [15].

In view of the short review of research given above, it is apparent that interruptions can have not only negative, but sometimes also positive influence on the performance after interruption. Hence, the question is how to prepare, modulate, or format the interruption to induce this positive outcome. Currently, this question is addressed by preparing different variations of interrupting content and evaluating their influence on the performance in recovery period in many dimensions, e.g., time or accuracy. These measures provide an answer which forms of interruptions have more positive impact on the subject than others but they do not provide any evidence to address “why” question. Meanwhile, if we were able to detect why a given interruption induces a positive or negative subject’s response, we would be able to prepare interruptions better suited to the subject’s expectations. We believe that in order to evaluate the true influence of the interruption on the subject during the recovery period we should use a more direct approach than measuring the time or accuracy—we should look insight the subject’s brain.

The paper reports the results of our preliminary experiment addressing the recovery from interruption phenomenon, conducted at West Pomeranian University of Technology in Szczecin. Two goals were posed in the experiment: first, establishing the influence of a simple 3-s visual interruption on the text reading process (in regard to text understanding and the time needed for completing the task), and second, investigating whether there is any consistency in the brain activity in the recovery after interruption period. At this stage of the survey we did not want to look for the reasons for positive or negative subject’s behavior in the recovery period; we wanted only to find out if the subject’s brain responded in a similar way for the similar interruptions.

The rest of the paper is organized as follows. Section 2 presents methods applied in the experiment. Two next sections, Results and Discussion, describe the output of the experiment and its analysis. And finally, the paper is summarized in the last section.

2 Experiment Setup and Methods

The experiment was performed with 14 subjects (students from the West Pomeranian University of Technology in Szczecin), 9 men and 5 women, aged between 20 and 25. All subjects were right-handed without any previous mental disorders. Before the experiment, each subject was fully informed about the experiment. The subjects were randomly assigned to two groups, called the treatment and the control groups, respectively. Before assigning subjects to groups, they were segmented according to the sex. After the assignment, the treatment group was composed of 4 male and 2 female, and the control group of 5 men and 3 women.

The experiment was composed of two stages. At both stages the subjects were presented with a text. The task was to read the text, understand it, and to answer a ten-question test, testing the level of text understanding. The text was presented in a computer screen as 10 short pages, each of the lengths of about 300 words. The decision when to display the next page was left for the subject (each page ended with a "move forward" button). No option to move back to previously read pages was available.

The difference in the experimental conditions for both groups was that while the control group was presented only with a pure text, in the treatment group, the process of reading a text was disturbed by advertisements presentation. Ten advertisements were displayed during the experiment, one per each text page. To avoid the habituation effect, the onset of each advertisement presentation was chosen randomly between 5 and 15 s after a new text page release. The period during which the advertisement was displayed on the screen was fixed (3 s).

The performance of the subjects from both groups was measured in two dimensions: the level of the text understanding and the time needed for completing the task. To test the level of text understanding subjects had to fulfill 10 yes/no questions' test. In order to draw the subject attention to the reading activity, the level of text understanding was evaluated at the end of the experiment. On the other hand, to make the subject more agitated during the advertisements presentation, the time needed to complete the whole experiment was measured. At the end of the experiment the subjects were ranked and awarded according to their results.

EEG data were recorded during the experiment, however, only from the subjects from the treatment group. Since there was any "disruption of the cognitive process" during the experiment with the control group, there was also nothing to investigate in their EEG signals. The EEG data were recorded from four monopolar channels at a sampling frequency of 250.03 Hz. Six passive electrodes were used in the experiments. Four of them were attached to subjects' scalp at Fp1, Fp2, F3, and F4 positions according to the International 10–20 system [16]. The reference and ground electrodes were placed at the right and left mastoid, respectively. The impedance of the electrodes was kept below 5 kΩ. EEG signal was acquired with EEG DigiTrack amplifier (Elmiko) and recorded with DigiTrack software.

In the signal preprocessing stage, a simple band-pass filter (1–30 Hz) was used. After filtering, the mean value was removed from each channel. Next, the epochs were extracted from the continuous signal recorded from a subject during the whole experiment. Each epoch started 3 s before the advertisement onset and ended 3 s after the advertisement offset. Hence, the epoch lasted 9 s; during the first 3 s the subject was reading the text, during the next 3 s he was looking at the advertisement, and during the final 3 s he was reading the text again. Since 10 advertisements were presented during the experiment, 10 epochs were extracted for each subject.

After extracting epochs, we inspected them visually in view of artifacts. We assumed that the data analysis would be done on the basis of at least 1 s of continuous recording. Therefore, we looked for the epochs that contained at least 1 s of artifact-free continuous data in each of the three segments (the first text reading, the advertisements presentation, and the second text reading). The visual inspection revealed that each epoch fulfilled our requirements, and hence all 10 epochs for all 6 subjects were accepted for the analysis.

In order to determine the brain activity patterns related to different stages of the experiment, we analyzed the changes in the signal power in six classic frequency bands: delta (1–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), low beta (13–18 Hz), medium beta (18–24 Hz), and high beta (14–30 Hz). For each frequency band, channel, and epoch, we calculated three values—the average signal power in the period when a subject was reading the first part of a text (PT1), the average signal power in the period when an advertisement was displayed (PA), and the average signal power in the period when a subject was reading the second part of the text (PT2).

To find out whether any significant effects appeared in the cortical activity recorded from a subject after removing the advertisement from the screen, we performed the statistical analysis of 10 epochs extracted for a subject. Since we wanted to know whether the "back to task activity" brought the statistically significant difference in each frequency band and each channel separately, we performed 24 (6 frequency bands $\times$ 4 EEG channels) paired t-student tests per testing condition. We performed two types of tests. The first one tested PT2 against PA, and the second tested PT2 against PT1. Hence, in the first group of tests we tested the null hypothesis H0: Average $(PT2_{ch,f})$ = Average $(PA_{ch,f})$ against the alternative hypothesis H1: Average $(PT2_{ch,f}) \neq$ Average $(PA_{ch,f})$, and in the second group of tests we tested the null hypothesis H0: Average $(PT2_{ch,f})$ = Average $(PT1_{ch,f})$ against the alternative hypothesis H1: Average $(PT2_{ch,f}) \neq$ Average $(PT1_{ch,f})$, where ch—channel index (ch = 1 ... 4), and f—frequency band index (f = 1 ... 6). The further analysis was performed for all pairs of averages where the null hypothesis was rejected, i.e., for all pairs where both averages differed significantly. To find out the direction of the change, we calculated the difference between the average value of PT2 and the average value of PA for the tests testing Average (PT2) against Average (PA) and the difference between the average value of PT2 and the average value of PT1 for the tests testing Average (PT2) against Average (PT1).

3 Results

Table 1 presents the results of the experiment in terms of execution time and text understanding. The execution time was measured separately for each text page and then was averaged for each subject. To make the execution time comparable for both groups, the time spent for advertisement presentation (three seconds) was subtracted from the average execution time calculated for subjects from the treatment group.

Table 1 Task performance for treatment and control group

Treatment group									
Subject	S1	S2	S3	S4	S5	S6			Avg
Average time (s)	31.10	28.96	38.03	25.55	30.25	30.46			31.28
Text understanding (%)	0.80	0.90	0.80	0.90	0.90	0.70			0.83
Control group									
Subject	S7	S8	S9	S10	S11	S12	S13	S14	Avg
Average time (s)	37.77	30.74	23.10	37.13	38.25	32.54	40.88	47.96	36.05
Text understanding (%)	0.90	0.60	1.00	0.80	0.80	0.80	0.90	0.80	0.83

Table 2 Brain activity patterns for subjects S1–S6 in BTT period compared to AD period and in BTT period compared to BA period

		BTT period versus AD period				BTT period versus BA period			
		Fp1	Fp2	F3	F4	Fp1	Fp2	F3	F4
S1	Low beta: 13–18 Hz						–		
	Medium beta: 18–24 Hz							–	
	High beta: 24–30 Hz			+					
S2	Theta: 4–8 Hz								+
S3	Delta: 1–4 Hz		–						
	Theta: 4–8 Hz 18–24 Hz		–						
	Low beta: 13–18 Hz				+				
S5	Medium beta: 18–24 Hz					–			
S6	Alpha: 8–13 Hz				+				

The text understanding was measured on the basis of the outcome from 10-question yes/no questionnaires fulfilled by the subjects after completing the reading task.

Table 2 presents brain activity patterns established for individual subjects in the back to task (BTT) period compared to the ads displaying (AD) period and compared to the before ads presentation (BA) period. The signs inside the table denote the direction of the change in the average signal power calculated over all 10 epochs. Symbol '+' means that the average signal power in the given frequency band and in the given channel was greater in BTT period; symbol '–' means that the average signal power was greater in AD or BA period. Only significant results, tested with paired *t*-student test are presented in the table. The comparison of the signal power of significant patterns for both pairs of periods is presented in Fig. 1 (BTT vs. AD period) and in Fig. 2 (BTT vs. BA period). As it can be noticed in both figures, in general brain activity patterns found for BTT versus AD period were stronger than those found for BTT versus BA period.

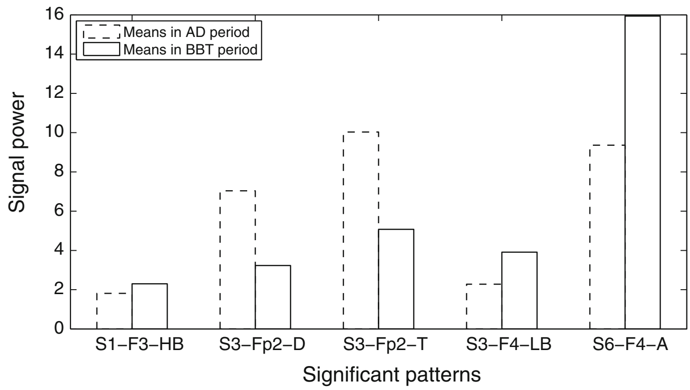

Fig. 1 The comparison of the signal power in BBT versus AD period for significant brain activity patterns; A-alpha, D-delta, T-theta, LB-low beta, MB-medium beta, HB-high beta

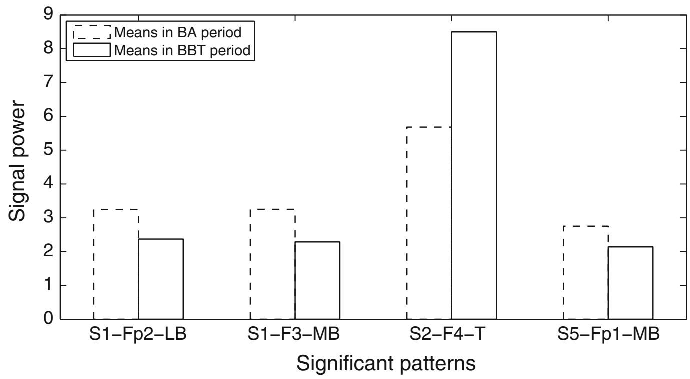

Fig. 2 The comparison of the signal power in BBT versus BA period for significant brain activity patterns; A-alpha, D-delta, T-theta, LB-low beta, MB-medium beta, HB-high beta

4 Discussion

The results presented in Table 2 can be summarized as follows:

1. The only significant difference in signal power observed for subject S1 was the increase in power in the high beta sub-band in channel F3 in BTT period compared to AD period, which suggests the approach motivation of the subject during back to task activity. At the same time, however, the drop in two beta sub-bands in both hemispheres was noted when comparing BBT period to BA period, which means that the subject was significantly less focused on the reading task in BBT period.
2. No significant changes in the brain activity over the analyzed channels were found for subjects S2, S4, and S5 when comparing BTT period and AD period. Two

significant changes observed in BTT period compared to BA period (an increase in the theta band for subject S2, and drop in the beta band for subject S5) indicate the drop in the concentration level BTT period, and the approach motivation of both subjects.

3. All three patterns found for subject S3 are consistent with each other. The drop in the signal power in two bands of the lowest frequency (delta and theta) over the right prefrontal cortex and the increase of the signal power in the beta band over the right frontal cortex clearly indicate the withdraw motivation of the subject.
4. Only one significant change in the signal power was found for subject S6—the increase in alpha band in the right frontal cortex in BTT period compared to AD period. This pattern indicates the approach motivation of the subject when he returned to the text reading task.

When we started our experiment, we believed that when the text reading process was interrupted by displaying ads, the total time needed for completing the task and the overall performance would be worse compared to the control group. However, after the analysis of related papers (discussed in Sect. 1), we abandon our first radical assumption, and started to expect that the subjects from the treatment group could achieve better performance than subjects from the control group. This assumption proved to be the correct one. As Table 1 presents, the average performance of the subjects from both groups was exactly the same. This means that interrupting of the text reading task by displaying 3-s ads did not bring any negative consequences for the task performance after interruption. Moreover, the time needed for completing the whole task was about 15 % shorter for the subjects whose concentration on the task was disrupted by displaying ads. These results are in line with those reported in [14]. Obviously, we do not state that this is the general truth because the effectiveness of backing to task depends on many factors, such as the length of the interruption, its invasiveness, the modality involved, etc.

The aim of our study was to find out whether this "back to task" activity has any reflection in the subjects' brains. In other words, we wanted to confront our time and performance metrics with the actual brain activity patterns. At first we assumed that when the subject successfully returns to his original task after interrupting it by ads presentation, the prefrontal and/or frontal parts of the brain should become more active. Hence, generally we expected the increase in the signal power in the beta sub-bands and decrease in the signal power in the alpha sub-bands. We expected also the overall drop in concentration during back to task activity, compared to BA period. After performing the experiments, it occurred, however, that none of the two assumptions were exactly valid. The first assumption, about the increase of the brain activity, was true only for two out of all six subjects (S1 and S3). For three of the remaining subjects (S2, S4, and S5) none of the significant changes were found in BTT period compared to BA period, and the only significant change found for the last subject (S6) suggested the drop, instead of the rise, of the brain activation.

What is really interesting here is that all three subjects whose brain activity remained on the same level during BTT and AD periods (S2, S4, and S5) performed significantly better than the average subject from both treatment and control groups

(Table 1). To be more precise, there was only one subject from the control group (S9) that performed better than these three subjects, and two subjects whose performance was on the same level (S7 and S13). Moreover, subjects S2, S4, and S5 also finished the whole task quicker than the average subject from both group. Also this time there was one subject from the control group who finished the task in a shorter time (S9), but the remaining 10 subjects were much slower in completing the task. In addition to lack of the significant patterns in BTT period compared to AD period, the analysis of BTT period compared to BA period performed for subjects S2, S4, and S5 revealed inactivation patterns with approach motivation for subjects S2 and S5, and no significant patterns for subject S4. One of the possible explanations why all three subjects performed better than most of the remaining subjects from both groups could be that they stayed on the same level of alertness during the whole task (S4) or even tried to improve themselves by being more agitated in BTT period than in BA period (S2 and S5).

While subjects S2, S4, and S5 performed better and quicker than most of the remaining subjects, subjects S1, S3, and S6 were less precise in their answers that the average subject from the treatment group. Their performance was also worse than the average performance of the subjects from the control group. The main difference between these three subjects and the subjects S2, S4, and S5 in terms of the brain activity patters is that all three "worse performing" subjects presented significant activity patterns in BTT versus AD period (as it can be noticed in Fig. 1 the differences in signal power in both periods were substantial). The patterns, however, were not consistent with each other. While the patterns found for two of the subjects (S1 and S6) indicated their approach motivation, the patterns found for subject S3 clearly indicated the withdraw motivation (Table 2, and Fig. 1). The approach motivation of subject S1 and S6 could mean that they were involved in the task and they wanted to proceed (and they did since their execution time was quick enough). Their alertness, however, could be too high to remember the details of the text. On the contrary, subject S3 presented negative attitude to the experiment and was rather not very interested in its continuation, which was in agreement with his achievements.

5 Conclusion

Summing up the results obtained in the experiment, it should be stated that the 3-s ads interrupting the reading task did not distract the subjects who returned to the main task with ease. Their average performance was on the same level as for the control group and they completed the whole task even quicker than subjects who were not disturbed by ads presentation. The main difference that was found in brain activity patterns between subjects whose performance was high and subjects who performed worse was the lack of significant patterns in the first group. Our assumption is that they stayed relax during the whole experiment and their brains were on the similar alertness level in all three analyzed periods. Due to this, they were able to perform the task better. In order to confirm this assumption, we plan to perform a full experiment on a much larger group of subjects. Moreover, in our future work we would like also to perform similar experiments with different forms of interruptions and other cognitive tasks to find the differences in brain activity patterns appearing during the successful and unsuccessful recoveries from interruption.

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