A Comparison and Analysis of Usability Methods for Web Evaluation: The Relationship Between Typical Usability Test and Bio-Signals Characteristics (EEG, ECG)

Haeinn Lee, St.Cloud State University, USA

Ssanghee Seo, Pusan National University, South Korea

Abstract

A usability assessment is now widely recognized as critical to the success of interactive interface design including web design. In this paper, our research team used a variety of different bio-signals such as Electroencephalogram (EEG), Electrocardiogram (ECG), and Electromyogram (EMG) to evaluate individuals' emotional reactions to different web interface designs. At the same time, we conducted typical usability testing of the same web interface design to compare the results of these two methods, and conclude whether usability testing using bio-signals is a good method to use for web evaluation.

Keywords

Web Interface Design; Usability Test and Method; EEG; ECG; ERP; Human Bio Signals; Visual Brainwork

On the web, usability plays a crucial role in user experience and is emphasized above anything else. It is an inherent design character and requirement, and closely related to various user errors (Rexfelt and Rosenblad, 2006; Latorella and Prabhu, 2000; Gramopadhye and Drury, 2000). Thus, usability testing is essential to create a well-designed web site that is highly usable, and measures a person's individual feeling and emotional satisfaction. Different usability evaluation techniques have been developed and incorporated into the design and development of web sites. Continuing study in this area, this paper shows a new and innovative method for usability testing, which classifies the emotional satisfaction of web interface design.

Typical user-based usability test and new method using bio-signals

Typical user-based usability test

Recently, it has been found that user-based testing is recommended to be the primary method in usability evaluations. The purpose of a usability test is to investigate whether a web interface design meets its usability requirements and problems it is addressing. Evaluating a web interface design helps to find out how successfully the design works, and what kinds of problems users have while using the interface design (Lee, 2006). This method is usually conducted in a scenario-based environment and includes user performance measurements, satisfaction questionnaires, interviews, and participator evaluations (Maguire, 2001; Gray and Salzman, 1998; Nielsen, 1993). With this method, the measures are easily obtained and can be used to infer problem areas in an interface design. This method, however, is too subjective and does not give any clear indication why a certain interface aspect poses a problem to a user or how to improve it (Jaspers, 2009). Therefore we focus on the strengths and weaknesses of typical user-based usability test.

New method of usability testing using bio-signals (EEG, ECG)

With advances in computer video display technologies, such as EEG, fMRI, PET, and SPECT, brain research has become a contemporary issue. Based on this issue, many different major areas, such as Medical Science, Engineering, Psychology, Biotechnology, Linguistics, Economics and Music explore diverse aspects of brain research. Hence, there should be many opportunities to study brain research relative to Art and Design.

When one makes the decision that something is good or bad, his or her decision is a result of the human thinking process. The brain works differently depending on a positive feeling or a negative feeling. In other words, the brain will answer in different ways when people look at effective designs or ineffective designs. One of my previous studies clarifies how the brain works when people look at good and bad design; it also comes up with an objective evaluation of how to judge the design value. Continuing this research, we are evaluating a person's emotion, mainly positive and negative feelings, by using a variety of different bio-signals such as EEG, and ECG.

Electroencephalogram (EEG): Many of the recent advances in understanding the brain are due to the development of techniques that allow scientists to directly monitor neurons throughout the body. EEG is the recording of electrical activity along the scalp produced by the firing of neurons within the brain (Society for Neuroscience, 2005). EEG has several strong components as a tool of exploring brain activity; for example, its time resolution is very high (on the level of a single millisecond).

Electrocardiogram (ECG): ECG is a transthoracic interpretation of the electrical activity of the heart over time captured and externally recorded by skin electrodes (Kumar). Electrical impulses in the heart originate in the sinoatrial node and travel through the intimate conducting system to the heart muscle. The electrical waves can be measured by electrodes placed at specific points on the skin. Electrodes on different sides of the heart measure the activity of different parts of the heart muscle. An ECG displays the voltage between pairs of these electrodes, and the muscle activity that they measure from different directions can also be understood as vectors. This display indicates the overall rhythm of the heart and weaknesses in different parts of the heart muscle. It is the best way to measure and diagnose abnormal rhythms of the heart (Braunwaid, 1997).

At the same time, we conducted a typical usability testing of the same web interface design to compare the results of these two methods, and concluded whether usability testing using bio-signals is a good method to use for web evaluation.

Methods

Participants and decision of web interface design

Ten healthy male college students in their twenties were selected for this experiment. After they agreed to the experiment, they completed questionnaires and we measured their brain waves and the electronic activity of the heart. The participants all consisted of persons who were right-handed and without brain-related diseases.

The websites evaluated were four different car companies' websites. Because of the subject issue, our research team chose all male participants who were interested in buying a car. In order to focus on design issues of web interface, the four websites chosen had brands of equal value and attractive design, but layout designs, navigation methods, and graphic elements were used in different ways. After the participants navigated the four websites, the preferred website was selected from the questionnaires given, and we compared them with the results of brain waves and electronic activity of the heart.

Usability testing procedure

The experiment included three main sessions: the user-based usability test, the EEG measurement, and the ECG measurement. Completing the usability test required approximately 60 minutes. All participants were involved in this research, and the scenario of the experiment is as follows:

1. Attach electrodes for EEG and ECG measurement
2. Show "+" on a computer screen for 4minute to ensure a steady state of participant's brain waves
3. Navigate Samsung SM5 web interface design and complete each task from the questionnaire during the next 10minutes
4. Show "+" on a computer screen for 1minute to ensure a steady state of participant's brain waves again.

5. Navigate GM Daewoo Tosca web interface design and complete each task from the questionnaire during the next 10minutes.
6. Show “+” on a computer screen for 1minute to ensure a steady state of participant’s brain waves again.
7. Navigate KIA Loche web interface design and complete each task from the questionnaire during the next 10minutes
8. Show “+” on a computer screen for 1minute to ensure a steady state of participant’s brain waves again.
9. Navigate Hyundai Sonata web interface design and complete each task from the questionnaire during the next 10minutes.
10. Show “+” on a computer screen for 1minute to ensure a steady state of participant’s brain waves again.
11. Participant chooses a mouse button (Yes: right button, No: left button) to decide whether he buys a Samsung SM5 car and we check event-related brain potentials (ERP).
12. Participant chooses a mouse button (Yes: right button, No: left button) to decide whether he buys a GM Daewoo Tosca car and we check event-related brain potentials (ERP).
13. Participant chooses a mouse button (Yes: right button, No: left button) to decide whether he buys a KIA Loche car and we check event-related brain potentials (ERP).
14. Participant chooses a mouse button (Yes: right button, No: left button) to decide whether he buys a Hyundai Sonata car and we check event-related brain potentials (ERP).
15. Participant fills out the user survey form for his preference of web interface design.

Procedure of typical user-based testing method

Usability assessment is now widely recognized as critical to the success of interactive interface design, including web design. Most common and typical usability testing is user-based evaluation that is based on user performance measurements, keystroke analyses, satisfaction questionnaires, and interviews. Using the four different web interface designs chosen, usability testing was conducted to analyze the user’s experience and performance. First, participants were asked for demographic information such as age, occupation, and their computer usage. Second, participants were asked to perform three tasks on the computer, and they had to finish all tasks navigating each car company’s website. Tasks were divided into specific questions such as checking each car’s model, shape, color, safety, performance, and price in order to find more accurate results. To accomplish these tasks, participants would navigate most of the websites. The software ‘Camtasia’ was used to capture a screen record and participants’ voices. Lastly, participants were asked to choose their preference of web interface design.

Procedure of usability testing using bio-signals method (EEG, ECG)

We also conducted usability testing using bio-signals, EEG and ECG, to evaluate individuals’ emotional reaction to different web interface designs in this research. Using the EEG method, electrodes placed on specific parts of the brain, which vary depending on which sensory system is being tested, make recordings that are then processed by a computer.

Our team has used the technique of EEG to address the question of how the brain answers while participants viewed websites. The most difficult decision when using EEG is which part of brain we need to place electrodes to measure the brain waves. Electrode location and names are specified by the 10-20 system for most research applications. This system is an internationally recognized method to describe and apply the location of electrodes in the context of an EEG test (Fig.1).

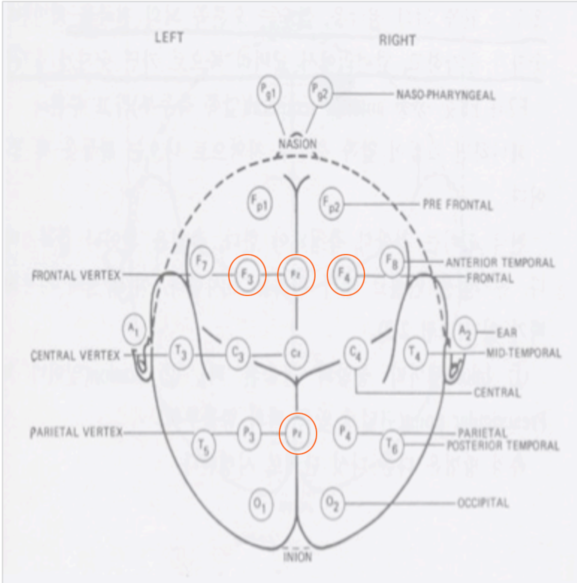

Figure 1 Electrodes location to check the EEG (10-20 System*)*

Brain waves were measured by QEEG-4 (LAXTHA) and 256Hz was selected for a sampling frequency. The position of electrodes went by the international 10-20 electrode arrangement, using the channels of F3 and F4 for emotional control area and Fz and Pz for decision making area. Standard electrodes were applied to Cz. The electrode arrangement plan is shown in Figure 1.

During the experiment, we used event-related brain potentials (ERP), which is a method in checking an electroencephalogram in certain moments when participants received the event, like choosing a mouse button to decide which car to buy. ERP is any measured brain response that is directly the result of a thought or perception. It can be reliably measured using the EEG, a procedure that measures electrical activity of the brain through the skull and scalp (Coles, Michael, and Rugg, 1996). There are four important components in the ERP waveform, which are P300, P600, P800 and N400. The N400 ERP component is described as a negative voltage deflection occurring approximately 400ms after stimulus onset, whereas the P300 component describes as a positive voltage deflection 300ms after stimulus onset. The presence, magnitude, topography and time of this signal are often used as metrics of cognitive function in decision-making processes.

Proper placement of the limb electrodes for ECG measurement is color coded as recommended by the American Health Association (Fig.2). Limb electrodes can be far down on the limbs or close to the hips/shoulders, but they must be even (left vs. right). Our research team attached electrodes like first figure and measured the electric waves of SDNN, the standard deviation of the normal RR intervals, and the ratio of high frequency (HF) and low frequency (LF) to check emotional status.

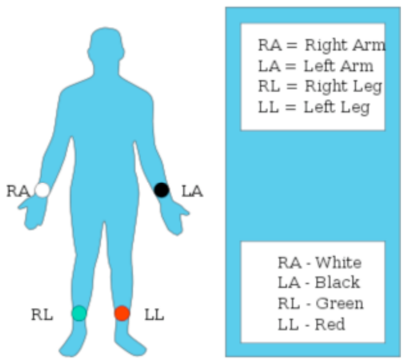

Figure 2 Electrodes location to check the ECG

Results

Analysis of typical user-based usability testing

Typical usability testing was user-based performance that was evaluated based on total time to complete tasks, number of errors, frequency of assists, and the percentage of completed tasks. Table1 shows the result of total time to complete task. The first column shows each participant and the first row shows the each website. Red texts show shortest time that participants had to finish all tasks from the websites.

	1	2	3	4	5	6	7	8	9	10
SM5	8.15	9.26	12.27	11.58	5.54	11.25	11.59	14.24	16.11	13.48
Tosca	6.54	7.37	7.44	8.05	5.54	8.34	8.35	7.13	16.08	12.19
Loche	**4.29**	**5.31**	**5.23**	**5.02**	**4.09**	6.25	**3.60**	**5.30**	**9.00**	**9.07**
Sonata	6.25	5.58	6.15	10.35	4.28	**6.00**	5.19	6.56	9.21	9.39

Table 1 Total time to complete tasks

	1	2	3	4	5	6	7	8	9	10
SM5	2	**0**	4	3	**0**	3	13	**1**	**2**	1
Tosca	2	4	3	**0**	5	8	5	3	5	**0**
Loche	**1**	3	2	**0**	3	**0**	**2**	3	3	5
Sonata	6	3	**1**	2	**0**	**0**	7	2	4	6

Table 2 Number of errors (Red texts show the lowest error)

	1	2	3	4	5	6	7	8	9	10
SM5	1	**0**	1	1	**0**	1	1	**0**	1	**0**
Tosca	1	1	1	**0**	**0**	1	1	**0**	**0**	**0**
Loche	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Sonata	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Table 3 Frequency of assists (Red texts show the lowest assist)

	1	2	3	4	5	6	7	8	9	10
SM5	100	100	100	100	100	100	100	100	100	**67**
Tosca	100	100	100	100	100	100	**67**	100	100	**67**
Loche	100	100	100	100	**67**	**67**	**67**	100	100	100
Sonata	100	100	100	**67**	100	100	100	**67**	100	100

Table 4 Percentage of completed tasks (Red texts show the less than 100%)

After analyzing the user-based usability testing results, we concluded the participant's preference of web interface design (Table5).

1	2	3	4	5	6	7	8	9	10
Loche	Loche & SM5	Loche & Sonata	Loche	Sonata & SM5	Sonata	Loche & Sonata	Loche	Loche	Loche & SM5

Table 5 Estimated participant's preference of web interface design from user-based usability testing

Lastly, Table6 shows the results from the user survey that participants directly answered the one, which they liked most among the four web interface designs. The results of Table 5 and Table 6 are mostly similar with few differences; therefore the user-based usability testing was successful.

1	2	3	4	5	6	7	8	9	10
Loche	SM5	Loche	Loche	Sonata	Sonata	Loche	Loche	Loche	Tosca

Table 6 Participant's preference of web interface design from user survey

Analysis of usability test using bio-signals (EEG, ECG)

First, we analyzed the ECG electric waves of SDNN, the standard deviation of the normal RR intervals, and the ratio of high frequency (HF) and low frequency (LF) to check emotional status. The higher number of SDNN means the participant's emotion is more active and positive. The lower number means there is no emotional feeling change. The higher number of HF means the participant's heartbeat is stronger which shows more active and positive feeling. Therefore, the smaller ratio of LF divided by HF is their preference website.

◇	A	B	C	D	E	F	G
1	date	subject	task	SDNN	LF	HF	LF/HF
32	06□ 25□	6. □□□	Open	44.8	75.6	24.4	
33			SM5	40.4	78	22	3.545455
34		X	Tosca	55.1	80.1	19.9	4.025126
35			Loche	47.3	81.9	18.1	4.524862
36			Sonata	60	81.1	18.9	4.291005
37							
38	06□ 26□	7. □□□	Open	53.2	77	23	
39			SM5	41.3	50.4	49.6	1.016129
40		X	Tosca	48.1	62.7	37.3	1.680965
41			Loche	31.7	74.8	25.2	2.968254
42			Sonata	33.9	79.4	20.6	3.854369
43							
44	06□ 26□	8. □□□	Open	52.9	40.5	59.5	
45			SM5	74.6	37.1	62.9	0.589825
46			Tosca	64.8	38.7	61.3	0.631321
47			Loche	79.8	51.1	48.9	1.04499
48		X	Sonata	59.5	43.3	56.7	0.763668
49							
50	06□ 26□	9. □□□	Open	52.1	74.5	25.5	
51			SM5	39.7	56.9	43.1	1.320186
52		X	Tosca	41.1	75.1	24.9	3.016064
53			Loche	60.8	73.8	26.2	2.816794
54			Sonata	58.6	72.7	27.3	2.663004
55							
56	06□ 29□	10.□□□	Open	66.3	84.4	15.6	
57			SM5	64.1	69.1	30.9	2.236246
58			Tosca	58.1	78.1	21.9	3.56621

Figure 3 Example of analyzing ECG data

	1	2	3	4	5	6	7	8	9	10
SDNN	Tosca	SM5	Sonata	Loche	Sonata	Sonata	Loche	Loche	Loche	SM5
LF/HF	Sonata	Loche	SM5	SM5	Loche	SM5	SM5	SM5	SM5	SM5

Table 7 Estimated participant's preference of web interface design from ECG

Second, we analyzed the EEG data, which a frequency of 4~30 Hz was selected to remove the noise from raw data, and the values of RPS (relative power spectrum) were found in the frequency band of brain waves, theta (4~8 Hz) and beta (13~30 Hz), using FFT (Fast Fourier Transform). As we mentioned previously, brain waves were measured by QEEG-4 (LAXTHA) and the position of electrodes went by the international 10-20 electrode arrangement, using the channels of F3 and F4 for emotional control areas.

Higher numbers of theta mean that people are a in comfortable and positive status, while higher numbers of beta mean that people are a in nervous and anxious thinking status. Thus, the F3 position is located in the left side of the brain, an area that processes optimistic thinking, and the F4 position is located in the right side of the brain, an area that processes pessimistic thinking. Therefore, we need to focus more on analyzing the F3 area for decision of preference of web interface design.

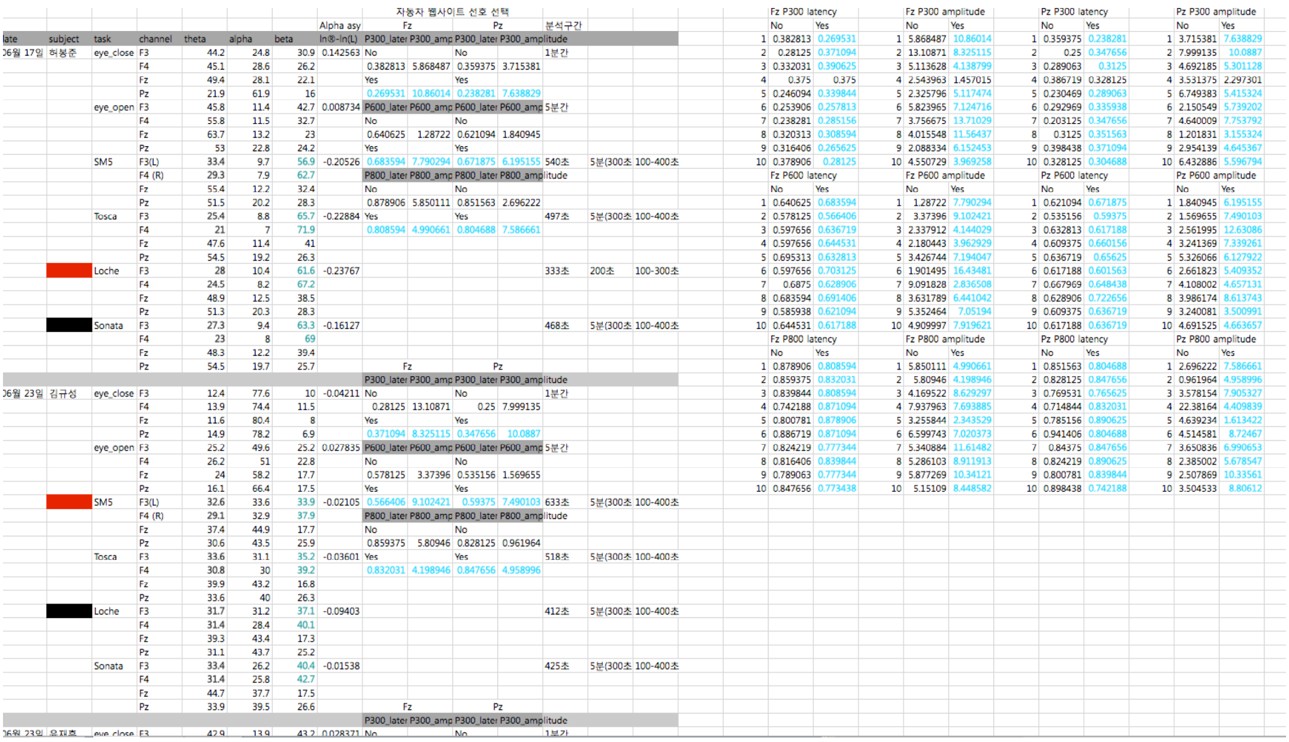

Figure 4 Example of analyzing EEG data

Figure 5 shows the result of beta power of F3 and F4. The red squares are the preference of web interface designs that participants chose from the user survey, and the black squares are the ones that they do not like. According to the figure of beta power of F3, most of their preference websites of beta power are lower than non-preference websites. As we mentioned previously, beta power shows the meaning of nervous and anxious thinking status, so this result is what we anticipated.

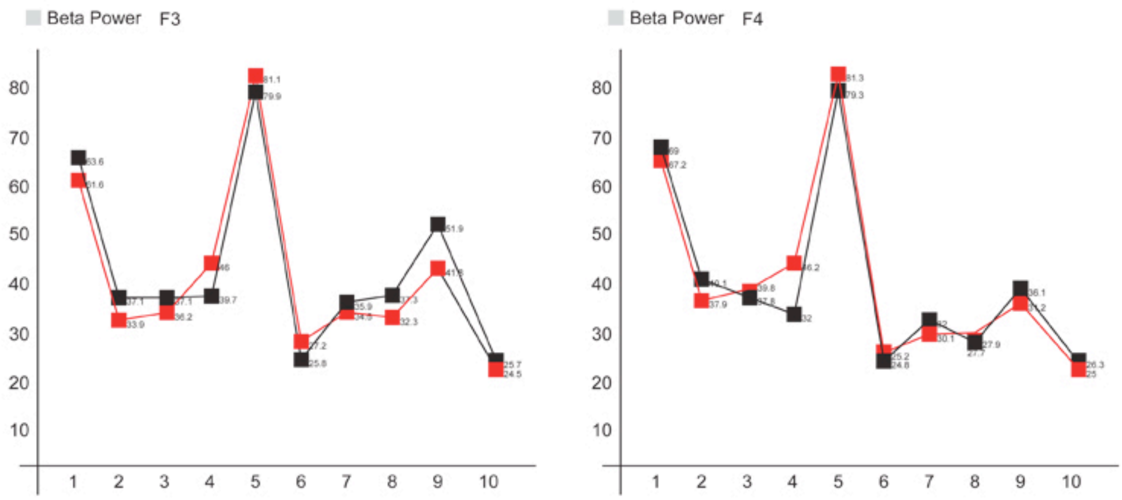

Figure 5 Result of beta power of F3 and F4

Figure 6 shows the result of theta power of F3 and F4. Again, the red squares are the preference of web interface designs that participants chose from the user survey, and the black squares are the ones that they do not like. According to the figure of theta power of F3, most of their preference websites of theta power are higher than non-preference websites. As we mentioned previously, theta power shows the meaning of comfortable status, so this result is what we anticipated.

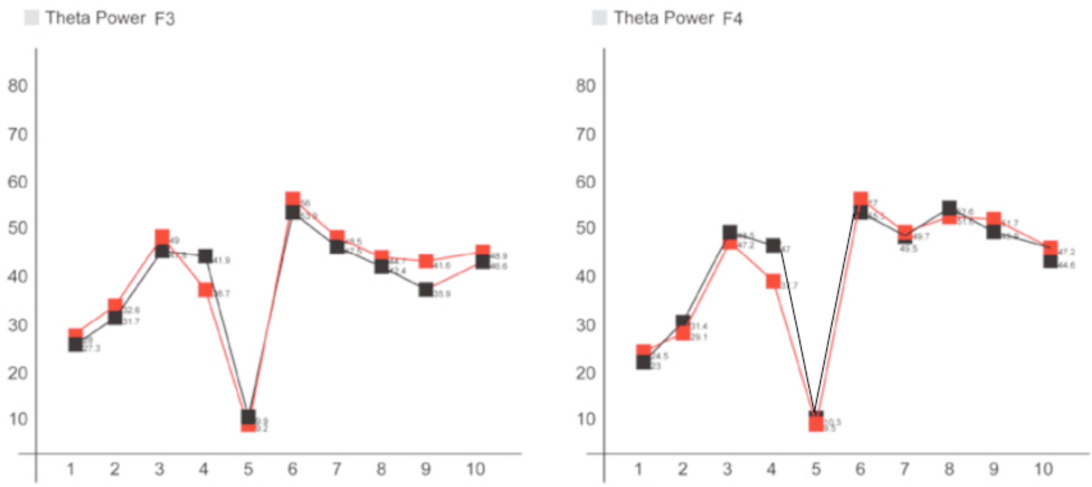

Figure 6 Result of theta power of F3 and F4

Additionally, we used event-related brain potentials (ERP), which is a method in checking an electroencephalogram in certain moments when participants received the event like clicking a mouse button (Yes: right button, No: left button) to decide which car to buy. Our research team attached the electrodes to Fz and Pz, which are areas for decision making.

Figure7 shows the P300, P600, and P800 of ERP results at the moment of participants clicked the preference of car. From the analysis, we concluded the amplitude of P600 shows the highest and strongest reactions when the participants chose preference of car.

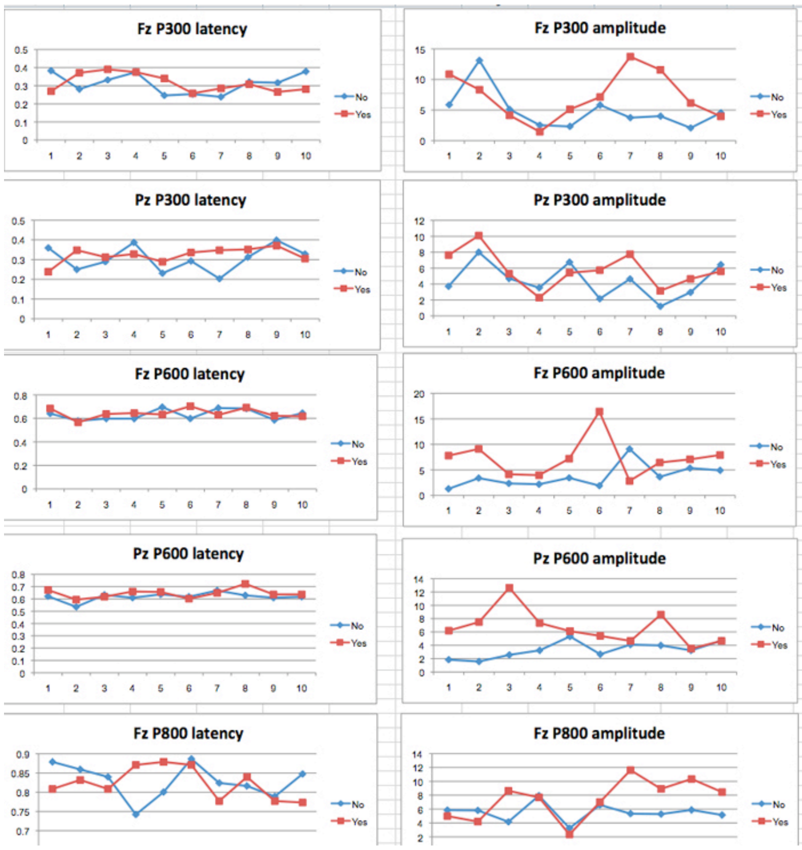

Figure 7 P300, P600, P800 of ERP result

Comparison and relationship of two methods

Table8 shows the results of the comparison between user-based usability testing, including the user survey and new usability testing methods using bio-signals (EEG, ECG). The final results of participants' preferences of car web interfaces consist through all different usability test methods, except the result of ECG (LF/HF). This result shows irregular choice of preference of car websites compared to other methods, and it is reasonable that we can eliminate it as final conclusion.

	1	2	3	4	5	6	7	8	9	10
User Survey	Loche	SM5	Loche	Loche	Sonata	Sonata	Loche	Loche	Loche	Tosca
User-based Usability testing	Loche	Loche & SM5	Loche & Sonata	Loche	Sonata & SM5	Sonata	Loche & Sonata	Loche	Loche	Loche & SM5
EEG:Theta Power	Loche	SM5	Loche	X	Sonata	Sonata	Loche	Loche	Loche	Tosca
EEG:Beta Power	Loche	SM5	Loche	X	X	X	Loche	Loche	Loche	Tosca
ECG: SDNN	Tosca	SM5	Sonata	Loche	Sonata	Sonata	Loche	Loche	Loche	SM5
ECG: LF/HF	Sonata	Loche	SM5	SM5	Loche	SM5	SM5	SM5	SM5	SM5

Table 8 Comparison of all methods

Conclusion

The purpose of a usability test is to investigate whether a web interface design meets its usability requirements and the problem it is addressing. Recently, it has been found that user-based testing is recommended to be the primary method in usability evaluations. With this method, the measures are easily obtained and can be used to infer problem areas in an interface design. However, sometimes it is too subjective and does not give any clear indication why a certain interface aspect poses a problem to a user or how to improve. To make up for this weak point, our research team used bio-signals (EEG, ECG) to evaluate individuals' emotional reactions to different web interface designs in this research.

Based on the result of typical user-based usability testing, we compared the result of new methods using EEG and ECG and it shows similar conclusion. Almost 70% of what participants chose the preference car website from typical-user based usability testing are the same result from the new method using bio-signals (EEG, ECG) which means reasonable and valuable method for web evaluation.

One of the most important issues in web interface design is a usability test to grasp a person's individual feeling and measure the emotional satisfaction. The web interface designs are also objectively assessed by measuring the degree of utilization of the design elements, clarifying how it affects their emotional feelings, and comparing it to the results of frequency from bio-signals. New design methods are required so web designers can grasp the proper emotion, impression, and feeling of a web interface, and reflect these elements to make better web interface design. In the future, the idea of this paper shows an innovative method for usability tests, which can classify emotional satisfaction of web interface design, also linked with ease of use.

References

Tan, W. Liu, D. Bishu, R. (2009). Web evaluation: Heuristic evaluation vs. user testing. *International journal of industrial ergonomics*, 39, 621-627. Elsevier.

Jaspers, W.M. (2009). A comparison of usability methods for testing interactive health technologies: Methodological aspects and empirical evidence. *International journal of medical information,* 78, 340-353. Elsevier.

Maguire, M. (2001). Methods to support human-centered design. *International journal of human – computer,* 55, 587-634.

Nielsen, J. (1993). Usability engineering. Cambridge MA: Academic Press.

Lee, H.I., Lee, J.T., Seo, S.H. (2009). Brain Response to Good and Bad Design, *Human Computer Interaction International*, Springer LNCS5610.

Choi,D.S., Lee, J.E., Kim, J.W.(2001). Empirical Study on Emotion-based Homepage Design

Zibell, K. (2000). Klare's Useful Information is Useful for Web Designers, *ACM Journal of Computer Documentation Vol24.*

Kim, M.Y., Cheng, H.I. (2004). Application of the Web Design Elements using the Aesthetic Evaluation, *Journal of Korean Society of Design Science* Vol.17 No.3.

Coles, Michael, G.H., rug, M.D. (1996). Event-related brain potentials: an introduction, Electrophysiology of Mind, Oxford scholarship Online Monographs, P1-27.

Society for Neuroscience(2005). Brain Facts, A primer on the Brain and Nervous System, http://www.sfn.org

Lee, J.Y. (2006). Neurophysiology and Brain-imaging study of Music-music & language, music & emotion, *Nangman Music Magazine* 18.

Mark, F., Barry, W., Michael, A.(2006). Neuroscience: Exploring the Brain (3rd), Lippincott Williams & Wikins.

West, W.C., Rourke, T., Holcomb, J.P. (1998). Event-Related Brain Potentials and Language Comprehension: A Cognitive Neuroscience Approach to the Study of Intellectual Functioning, Tufts University.

Lu, H., Wang, M., Yu, H. (2005) EEG Model and Location in Brain when Enjoying Music: *Proceedings of the 2005 IEEE Engineering in Medicine and Biology*, pp.2695-2698. Shanghai, China.

Wikipedia, encyclopedia: http://en.wikipedia.org/wiki/EEG

Braudwald, E. (1997). heart Disease: A textbook of cardiovascular medicine,5th, P.108, Philadelphia:W.B. Saunders Co.

Gray, W. D., & Salzman, M.C. (1998). Damaged merchandis? A review of experiments that compare usability evaluation methods, *Human-computer interact.* 13, 203-261

Author Biography

Haeinn Lee

Haeinn Lee is an assistant professor of Graphic Design at St.Cloud State University where she teaches typographic design and information & interface design. She received her MFA degree in Graphic Design at Iowa State University. She has presented her research and design works in conferences both nationally and internationally. Her research interest focuses on experience design, typographic design, user research and brain works based on graphic design.

Ssanghee Seo

Ssanghee Seo is an associate researcher of BK center for U-Port IT research and education at Pusan National University. She received Ph.D. degree at Kyungnam University in 2000. She was included in MARQUIS Who's who in the World 2010, IBC 2010 and ABI 2010 on brain engineering. Her research interest focuses on brain-computer interface and pain control using rTMS.