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Integrating TAM with EEG Frontal Asymmetry

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Abstract: Recent evolution in the Information Systems (IS) community has involved neuroscience tools and methods in order to develop new theories concerning Human-Computer Interaction (HCI) and further understand IS acceptance models. Thus, the field of NeuroIS has emerged. Moreover, NeuroIS researchers have proposed encephalograph (EEG) as valuable usability metric. Particularly, EEG frontal asymmetry has been related to approach/withdraw behaviour and positive/negative affect concerning users' perceptions. Furthermore, Technology Acceptance Model (TAM) has been established as the most notable model regarding IS acceptance. This study is a first attempt to integrate EEG frontal asymmetry with TAM in order to associate brain activation with the two most important variables of TAM: Perceived Usefulness and Perceived Ease of Use. Specifically, thirty one undergraduate students were chosen to use a Computer-Based Assessment (while being connected to the EEG) in the context of an introductory informatics course. Results indicate a direct positive association of frontal asymmetry on the aforementioned variables. These findings suggest that frontal asymmetry could be useful for validating and developing Information Technology (IT) theories, as well as designing and explaining the acceptance and adoption of new IS systems or products.

Keywords: TAM, EEG frontal asymmetry, Perceived Usefulness, Perceived Ease of Use.

1 INTRODUCTION

In recent years, Information Systems (IS) researchers have introduced a new field called NeuroIS (Dimoka et al., 2007). NeuroIS uses methods and practices of neuroscience in order to better understand how human and IS interactions work, or to develop new theories regarding IT-related behaviors (Riedl et al., 2010a).

Cognitive neuroscience uses a variety of tools such as Functional Magnetic Resonance Imaging (fMRI), Electroencephalography (EEG), Positron Emission Tomography (PET), and Skin Conductance Response (SCR). These tools, when used effectively in appropriately designed experiments, could provide invaluable brain and psychophysiological data in order to accelerate comprehension of human behavior in the context of many different fields, such as IT usage, economics, psychology, and marketing (Glimcher et al., 2009). Although combining and synchronizing two or more tools during such experiments could greatly increase the quality of data, numerous researchers have conducted experiments employing only EEG methods. The main advantages of EEG are that it is a relatively low-cost, quick, and safe way to examine functioning of different areas of the brain (Davidson, 1988).

EEG measures the electrical cortical activity using electrodes placed on the scalp. When used in NeuroIS experiments EEG can be a useful usability metric

Numerous researchers have shown that relatively greater left frontal activity is associated with positive affect and approach-related motivation, and that relatively greater right frontal activity is associated with negative affect and withdrawal-related motivation (Harmon-Jones, 2003).

However, research has suggested that the valence of an emotion may be distinguishable from the motivational direction of that emotion, so that emotions of negative valence, such as anger, can be approach motivating (Harmon-Jones, Gable, &. Peterson, 2010). In this regard, research evidence has associated left-lateralized prefrontal activity with higher levels of reported anger (Harmon-Jones, 2003). What is important here is that asymmetric frontal cortical activity is certainly tracking approach motivation, regardless of the emotional valence of that motivation (Harmon-Jones, Gable, &. Peterson, 2010). This, however, can have serious implications when using frontal asymmetry to define IS acceptance variables.

Moreover, research has confirmed that EEG activity within the alpha band (8–12 Hz) is inversely related to underlying cortical activity, since decreases in alpha are likely to be measured when the underlying cortical systems move to active processing (Coan & Allen, 2004). Thus, in the EEG literature left frontal vs. right frontal activation is indicated by lower EEG power values in the alpha frequency band. One of the first reports that associated left-frontal reduction in the quantity of the alpha bandwidth with positive affect was that of Davidson, Taylor, and Saron (1979). On the contrary, negative affect was related to a reversal of the frontal alpha ratio score.

This study examines how alpha frontal asymmetry at medial (F3-F4) and lateral frontal (F7-F8) scalp locations can explain the most important variables of IT acceptance, since especially those asymmetry scores have been shown to be related to emotion-connected and approach-oriented/withdrawal-oriented behaviours (Coan, Allen, 2003; Davidson & Fox, 1989; Davidson et al., 1990; Dawson, Panagiotides, Klinger, & Hill, 1992; Harmon-Jones, Harmon-Jones, Serra, Gable, 2011; Fox, 1994; Fox et al., 2001). Asymmetry calculated at other frontal locations may also provide useful explanation of IT acceptance variables.

Specifically, this paper focuses on changes at F3-F4 and F7-F8 asymmetry scores during the use of a Computer-Based Assessment (CBA) and whether these changes could explain user perceptions regarding Usefulness, Ease of Use and potentially behavioral intention to use the CBA. Therefore, this study contributes to the NeuroIS field by employing EEG frontal asymmetry scores in order to explain the most notable model regarding IT acceptance, the Technology Acceptance Model (TAM) (Davis, 1989).

The organization of this paper is the following: In section 2, related studies in NeuroIS are briefly presented. Section 3 presents the proposed model. Section 4 describes the experimental method. Section 5 demonstrates the data analysis (EEG and research questionnaire data) and the results. Finally, section 6 discusses the research findings and presents implications, limitations, and conclusions of this study, as well as directions for further research.

2 RELATED RESEARCH

The first studies related to NeuroIS focused on explaining how neuroscience could be beneficial for IS field. Fifteen authors built the foundations of NeuroIS by discussing major questions such as (1) What is NeuroIS,? (2) Which neuroscience tools are important for IS field? (3) How neuroscience could help IS researchers? (4) Potential IS topics that could benefit from neuroscience tools (Riedl et al., 2010a). Moreover, we could find other studies aiming to shed light in the novel research area of NeuroIS by presenting the opportunities developed through the combination of IS and Neuroscience.

Dimoka (2010) pointed out seven opportunities regarding the use of neuroscience in IS: (1) Detect the correlation of IS constructs with specific neural mechanisms; (2) Combine IS data with neuroscientific data; (3) Detect new processes that could not be measured through traditional measurements; (4) Measure brain activation caused by IT stimuli to determine antecedents of IS constructs; (5) Use brain activation to predict perceptions and behavior regarding IS constructs; (6) Investigate the timing of brain activations in order to define causality among IS constructs; (7) Question and improve existing IS theories through brain's functionality.

Recently, Liapis and Chatterjee (2011) proposed the NeuroIS Design Science Model (NDSM). NDSM is a promising framework towards the better understanding of human and interface interaction which will produce more efficient technological artifacts. (2011)

Another group of studies provided the first results regarding NeuroIS. These studies used mainly FMRI and EEG to collect data. Two studies provided useful information regarding the possibility of locked-in patients (people who are totally paralyzed and not capable of speaking, but cognitively unharmed) through brain-computer interfaces (Moor et al. 2005, Randolph et al. 2006). Moreover, physiological measurements were implicated for measuring stress regarding internet users (Galletta et al. 2007). In addition, FMRI was used in two studies related to the trust variable in IS. The first study used FMRI to display gender differences regarding trustworthiness on e-commerce through brain activity (Riedl et al., 2010b). The second study provided evidence regarding the distinction of trust and distrust in e-commerce through the activation of different brain areas (Dimoka, 2010). On the other hand, EEG was used to define computer user's engagement on a specific mental task at a particular point of time (Lee & Tan, 2006).

Researchers also investigated the correlation of the two most important variables of TAM with specific neural and brain areas (Dimoka and Davis, 2008). The aforementioned study triggers and inspires our study which will try to shed light on how EEG measurements and especially frontal asymmetry could be used to define and predict user's perceptions regarding Usefulness and Ease of Use.

3 PROPOSED MODEL

3.1 Perceived Usefulness

Perceived Usefulness (PU) is the first of the two most important determinants of technology acceptance (Davis, 1989). Perceived Usefulness is determined as the degree to which a person perceives that using a particular system will increase his/her job performance (Davis, 1989). Previous studies provided strong evidence of the positive effect of Perceived Usefulness on the Behavioral Intention to use an e-learning system or a CBA (e.g. Lee, 2008; Ong & Lai, 2006; Terzis & Economides, 2011). Thus, we expect that Perceived Usefulness will be a strong determinant of Behavioral Intention to Use CBA. Therefore, we hypothesized (Figure1):

H1: Perceived Usefulness will have a positive effect on the Behavioural Intention to use CBA.

3.2 Perceived Ease of Use

Perceived Ease of Use (PEOU) is determined as the degree to which a person perceives that using the system would be free of effort (Davis, 1989). Many researchers provided evidence that the Perceived Ease of Use directly influences Behavioral Intention to Use an e-learning system or a CBA (Agarwal & Prasad, 1999; Terzis & Economides, 2011; Venkatesh, 1999; Venkatesh & Davis, 1996). Thus, we hypothesized (Figure1):

H2: Perceived Ease of Use will have a positive effect on the Behavioural Intention to use CBA.

3.3 Frontal Asymmetry

As discussed earlier in the introduction, left frontal vs. right frontal activation is indicated by lower EEG power values in the alpha frequency band. Previous studies have suggested that the difference of alpha frequency in frontal cortex is associated with individual's positive vs. negative perceptions and approach/withdraw motivation regarding the stimuli (Davidson, Taylor, and Saron, 1979).

The aforementioned phenomena could be aroused (among other factors) during CBA by the system's ease of use and usefulness. Thus, for instance, we would expect that students who had a greater approach motivation (as indicated by greater left frontal activation), during their interaction with the system, would also report a greater sense of usefulness and ease of use. Consequently, we assumed that greater left vs. right frontal activation would be positively associated with users' perceptions regarding usefulness and ease of use, while answering the questionnaire after the end of the CBA. Therefore, we hypothesized that (Figure1):

H3: Frontal Asymmetry will be positively associated with Perceived Usefulness.

H4: Frontal Asymmetry will be positively associated with Perceived Ease of Use.

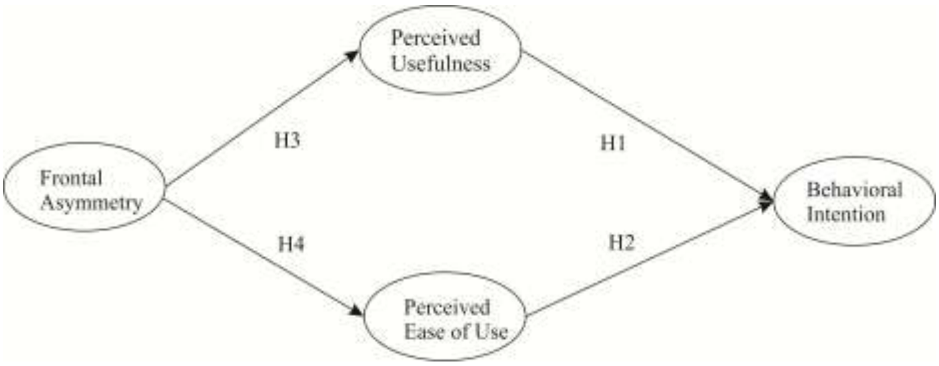

Figure 1. The research model.

4 METHOD

4.1 Participants

Participants were first year undergraduate students enrolled in an introductory informatics course. Students were told that they could optionally participate in a Computer-Based Assessment (CBA) to help them assess their knowledge before the final exam. Students who took up this option (about two thirds of the class), were then asked to voluntarily to use the CBA while connected to EEG in order to serve as subjects of a research study (subjects were not specifically informed about the purpose of the study). Those who volunteered completed a short survey and signed an informed consent. Only volunteer students who were right handed, in good mental health (don't take medication that affects the central nervous system) and had normal or corrected to normal vision were chosen. The sample was limited to right-handed participants because hemispheric specialization has been identified to be different in left-handed subjects. Thus, 33 subjects in total were selected to participate in the current stage. However, 2 of them changed their mind about being connected to the EEG while taking the CBA, which resulted in 31 participants (15 males and 16 females). Participants were instructed to sleep sufficiently and not to consume any alcohol related product the night before the experimental procedure.

4.2 Procedure

Each participant was tested individually. Electrodes were appropriately placed on subject's scalp and the EEG was adjusted accordingly (see section 5.1). After that the participant used the CBA. The CBA test consisted of 20 multiple choice questions and students had to complete the test in 20 minutes. . The questions appeared random and each question had 4 possible answers. Student had to answer each question in order to be appeared the next question. CBA was delivered through an Apache web server with MySQL and it was programmed with Perl CGI and JavaScript (Moridis & Economides, 2009). When participants finished the test, they were disconnected from the EEG and were given a few minutes to relax. Participants then completed a questionnaire, in order to examine the 3 latent variables of the model. For the 3 latent variables, we adopted 3 items regarding Perceived Usefulness, 3 items for Perceived Ease of Use and 3 items for Behavioral Intention to use from Davis (1989), modified to be relevant in CBA context (Terzis & Economides, 2011). All items were measured on a seven point Likert-type scale with 1 = strongly disagree to 7 = strongly agree.

5 DATA ANALYSIS AND RESULTS

5.1 EEG recording, reduction and analysis

The recordings took place in a calm room, while at least 6 min of eyes open-eyes closed EEG data were collected from the 19 monopolar electrodes sites (Fpl, Fp2, F3, F4, F7, F8, Fz, C3, C4, Cz, T3, T4, T5, T6, P3, P4, Pz, 01 and 02 sites) (Figure 2). The purpose of this recording was to have the chance to correct any technical problems before the real recordings when the students were using the CBA. The international 10/20 System (average reference montage) for electrode placement was used with a Neuron-Spectrum-4 (Neurosoft-Medical Diagnostic Equipment, Russia). All electrode impedances were less than 5 kΩ, while the sampling rate for all measurements was 500 Hz.

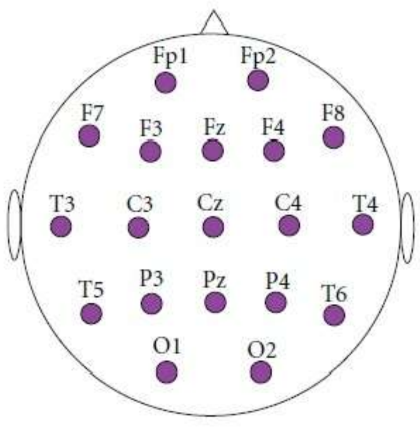

Figure 2. Scalp EEG electrodes.

EEG records were visually examined by three independent experts and sites which contained movement and muscle artifacts were marked and excluded from further analysis. Then, Independent Component Analysis (ICA) from EEGLAB was applied to identify and remove more sources of artifacts (Delorme and Makeig, 2004). After that, the EEG records were examined again by three independent experts in order to confirm whether artifacts had been successfully removed.

Thus, at least 8 min of artifact-free data were extracted from each participant's EEG total record for quantitative analysis. A typical Power Spectral Density (PSD) estimator was applied (based on the squared absolute value of the Fourier Transform) with Hamming windowing. Average alpha (8–12 Hz) power (microvolts squared) was after that natural log transformed in order to normalize the distributions of power values, as these distributions tend to be positively skewed. This practice has been widely used and follows the recommendations of Davidson et al. (1990). Finally, frontal EEG asymmetry scores associated with medial (F3-F4) and lateral frontal (F7-F8) scalp locations, were calculated for alpha band following the methodology described by Davidson (1988):

$$\frac{Right - Left}{Right + Left} \quad (1)$$

The difference in score hence gives a simple scale (1) accounting for the relative activity of the right and left hemispheres, with higher scores indicating relatively greater left frontal activity (alpha is inversely related to activity) (Allen, Coan, Nazarian, 2004). Thus, a value of 0.5 would represent a strong 50% right side asymmetry and therefore considerable left side activation.

5.2 PLS analysis and results

This study used partial least-squares (PLS) analysis to analyze the measurement and the structural model. PLS is suitable for our study since we have small sample (Chin, 1998; Falk & Miller, 1992) and we are testing a new theory in early stages of development (Fornell & Bookstein, 1982). The minimum recommended value regarding sample size equals to the larger value of the two following guidelines: (a) 10 times larger than the number of items for the most complex construct; (b) 10 times the largest number of independent variables impact a dependent variable (Chin, 1998). In our case, the most complex construct has 3 items (eg. Perceived Usefulness), therefore our sample of 31 individuals is considered as trustworthy. Data analysis for the measurement and structural model was conducted with SmartPLS 2.0 (Ringle,Wende, & Will, 2005).

The reliability and the validity of the measurement model are defined through the internal consistency, convergent validity and discriminant validity. Specifically, our results have to satisfy four requirements: a) The first is a value higher than 0.7 regarding items' factor loading on the corresponded constructs. b) A value higher than 0.5 regarding Average Variance Extracted (AVE) of each variable. c) AVE's squared root of each construct should be larger than any correlation with every other construct (Barclay et al., 1995; Chin, 1998; Fornell & Larcker, 1981). d) A value higher than 0.7 regarding composite reliability (Agarwal & Karahanna, 2000; Compeau, Higgins, & Huff, 1999).

Tables 1 and 2 display the results regarding the aforementioned measurement model's requirements. Table 1 confirms that factor loadings, composite reliability and AVE of each construct satisfied the minimum recommended values respectively. Thus, the internal consistency and the convergent validity are verified. In addition, table 2 shows the constructs' correlations among them, while the bold diagonal elements are the square root of each construct's AVE. All the AVEs are higher than any other correlation, therefore we could support that discriminant validity is verified. Thus, the reliability and the validity of the measurement model are supported from the data.

On the other hand, the structural model is verified firstly by examining the significance of the path coefficients through the bootstrapping procedure and t-values calculation and secondly by examining the variance measured (R2). Regarding variance measurements, Cohen (1988) proposed 0.2, 0.13 and 0.26 as small, medium and large variance respectively.

Table 3 and figure 3 summarize the results for the hypotheses. In agreement with prior studies, we find that Perceived Usefulness and Perceived Ease of Use are strong determinants of Behavioral Intention to Use. Furthermore, the data indicate a direct positive effect of frontal asymmetry on Perceived Usefulness and on Perceived Ease of Use. Thus, all the hypotheses were supported. Moreover, frontal asymmetry has strong indirect effect through Perceived Usefulness and Perceived Ease of Use on

Behavioral Intention by 0.31. Finally, the model explains almost the 74 % of variance in Behavioral Intention to Use.

The results were almost the same for medial (F3-F4) and lateral (F7-F8) frontal asymmetries. The results for the measurement model were the same except from the mean and standard deviation. The values in discriminant validity for the measurement model also remained similar for medial and lateral frontal asymmetries. Regarding the structural model, F7-F8 lateral frontal asymmetry path coefficients on Perceived Usefulness and Perceived Ease of Use were slightly different than F3-F4 medial frontal asymmetry (Table 3, Figure 3).

Construct Items	Mean	Standard Deviation	Factor Loading	Cronbach a	Composite Reliability	AVE
Behavioral Intention to Use	5.85	0.99		0.95	0.97	0.90
BI1			0.96			
BI2			0.95			
BI3			0.94			
Perceived Usefulness	5.75	0.96		0.89	0.93	0.82
PU1			0.88			
PU2			0.93			
PU3			0.89			
Perceived Ease of Use	5.67	0.99		0.93	0.95	0.87
PEOU1			0.91			
PEOU2			0.93			
PEOU3			0.94			
Medial-Frontal asymmetry F3-F4	-0.33	2.28		1	1	1
Lateral-Frontal asymmetry F7-F8	-0.54	5.74		1	1	1

Table 1. Results for the Measurement Model.

Construct	Behavioral Intention to Use	Perceived Usefulness	Perceived Ease of Use	Medial/ Lateral Frontal asymmetry
Behavioral Intention to Use	0.95			
Perceived Usefulness	0.84	0.93		
Perceived Ease of Use	0.83	0.89	0.90	
Medial/ Lateral Frontal asymmetry	0.15	0.36	0.34	1

Table 2. Discriminant validity for the measurement model

Hypothesis	Path	Path coefficient		t value		Results
		F3 – F4	F7-F8	F3 – F4	F7-F8	
H1	PU → BI	0.41*	0.41*	1.90	1.95	Support
H2	PEOU → BI	0.47**	0.47**	2.08	2.09	Support
H3	FA → PU	0.34***	0.35***	2.92	3.37	Support
H4	FA → PEOU	0.36***	0.37***	2.68	3.71	Support

*Table 3. Hypothesis testing results, *p < 0.1, **p < 0.05, ***p < 0.01.*

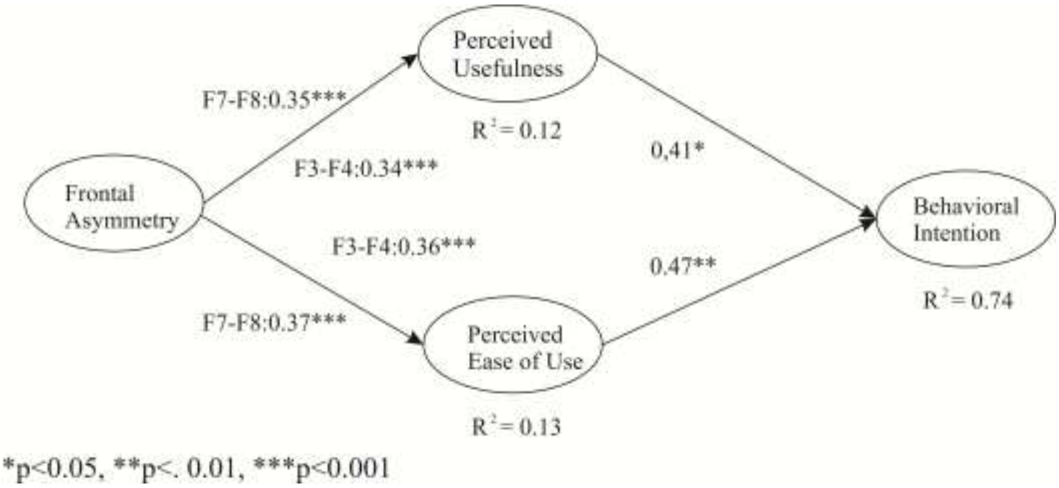

Figure3. Path coefficients of the research model.

6 DISCUSSION AND CONCLUSIONS

This study indicated that frontal asymmetry explains student's perceptions regarding usefulness and ease of use. Overall, results presented in this research showed that the more students' left frontal cortex was activated during their interaction with the CBA, the more they described their experience with the system as useful and easy to use. In this approach, the frontal cortex plays a key role in the neuroIS research since the neural activity in these areas seems to determine the two most important variables of IS acceptance.

The data revealed several interesting findings which may be useful to: (1) The development of new theories; (2) The developers regarding the designing, acceptance and adoption of new software and hardware systems; (3) Educators and business practitioners by providing new aspects regarding their IS systems or products.

However, this study has some limitations. As one of the first attempts for the development of an acceptance model using physiological data, the results of this study should be treated as indicative and not as conclusive. Future studies should further investigate the association of frontal asymmetry with important IS acceptance variables. Secondly, this research used a very specific sample of students to respond regarding their beliefs. The proposed model has to be applied in other groups with other characteristics (e.g. age, occupation) or organizations (e.g. companies) for further confirmation. Thirdly, even if we have employed PLS analysis which is appropriate for small samples, this study might have benefit from a larger sample. Perhaps the most debatable limitation of this study concerns the circumstances of the experiment. Obviously, the situation is artificial, because in real life students sit in front of their computers in a more comfortable and calm environment, without electrodes placed on their scalp. Nevertheless, it has not yet been defined whether this limitation weakens or enhances the actual results.

In the future, we intend to follow a gender specific approach in order to gather data that could provide useful explanation of males and females differentiation regarding frontal asymmetry and their perceptions while interacting with an IS system. Moreover, this approach could help confirm or further expand points of theory about gender differences concerning IS acceptance variables. Furthermore, we also plan to extend this study by taking into consideration other user's characteristics such as gender, occupation, culture and results from other frontal asymmetry scalp locations (e.g. FP1-FP2).

Brain-waves based procedures would significantly enrich information systems acceptance research portfolio and help developers evaluate their systems. The integration of EEG-based research with EMG, GSR, FMRI and traditional self-report methods would provide innovative explanations in the context of IS acceptance.

To conclude this research study is essential towards understanding further the practical use of neuroscience research in information systems. In particular, this study presents EEG frontal asymmetry as a potential neurophysiological tool to measure user's perceptions regarding system's usefulness and ease of use.

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