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The Potential of Neuroscience for Human-Computer Interaction Research

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ABSTRACT

Due to the increased availability of both neuroscience methods and theories, Information Systems (IS) scholars have begun to investigate the potential of neuroscience for IS research. This new field of research is referred to as NeuroIS. Moreover, large technology companies (e.g., Microsoft and Philips) started research programs to evaluate the potential of neuroscience for their business. The application of neuroscientific approaches is also expected to significantly contribute to advancements in human-computer interaction (HCI) research. Against this background, a panel debate is organized to discuss the potential of neuroscience for HCI studies. The panel hosts an intellectual debate from different perspectives, both conceptually (from behaviorally-oriented research to design science research) and methodologically (from brain imaging to neurophysiological techniques), thereby outlining many facets that neuroscience offers for HCI research. The panel concludes that neuroscience has the potential to become an important reference discipline for the field of HCI in the future.

Keywords

Brain, Human-Computer Interaction, NeuroIS, Neuroscience

INTRODUCTION

Due to the increased availability of neuroscience methods and theories, scholars have begun to investigate the potential of neuroscience for information systems (IS) research. The term *NeuroIS* has been coined to describe the "idea of applying cognitive neuroscience theories, methods, and tools to inform IS research" (Dimoka et al., 2007, p. 1). During the past years, NeuroIS has emerged as a new subfield within the IS discipline, defined as follows (Riedl et al. 2010a, p. 245): "NeuroIS is a subfield in the IS literature that relies on neuroscience and neurophysiological theories and tools to better understand the development, use, and impact of information technologies (IT). NeuroIS seeks to contribute to (i) the development of new theories that make possible accurate predictions of IT-related behaviors, and (ii) the design of IT artifacts that positively affect economic and non-economic variables (e.g., productivity, satisfaction, adoption, well being)."

Considering this definition, it is obvious that the application of neuroscience methods and theories can significantly contribute to scientific progress in human-computer interaction (HCI) research. Moreover, the appeal of neuroscience is not confined to academia (e.g., Riedl and Müller-Putz, 2010). For example, Daimler-Chrysler used functional magnetic resonance imaging (fMRI) to gain insights on how to improve their car design. Microsoft, to state another example, has started to investigate the potential of brain-computer interaction based on electroencephalography (EEG) technology in human-computer interaction. Philips, another well-known company, recently presented an emotion sensing system based on galvanic skin response technology (GSR) which alerts online home investors "when it may be wise to take a time-out, wind down and re-consider their actions" (www.design.philips.com), thereby using biological information in human-computer interaction. Finally, the video gaming industry has been using EEG-based headsets for a while to capture the brain's electrical states while playing games (see, for example, www.emotiv.com and www.neurosky.com).

Considering both the recent efforts in research and practice to integrate neuroscience and IS research, and the importance of the HCI field within the IS discipline, the *AIS Special Interest Group on Human-Computer Interaction (SIGHCI)* invited René Riedl to organize a panel discussion on the potential of neuroscience for HCI research. In his role as the panel organizer and chair, René

Riedl invited both IS and neuroscience scholars to serve as panelists. The following experts accepted the invitation: Adriane B. Randolph, Jan vom Brocke, Pierre-Majorique Léger, and Angelika Dimoka (mentioned in the order in which they give their presentations during the panel debate). Considering the various scientific backgrounds of the panelists, the discussion hosts an intellectual debate from different perspectives, both conceptually (from behaviorally-oriented research to design science research) and methodologically (from brain imaging to neurophysiological techniques).

Moreover, the discussion complements the existing literature on neuroscience and HCI research (e.g., Minnery and Fine, 2009), thereby offering an expanded view on this new and promising stream of research.

The structure of the present article reflects the structure of the main parts of the panel discussion and is organized along the following thematic lines:

- Brain-Computer Interaction: A New Direction in HCI *by Adriane B. Randolph*
- Neuroscience and Design Science Research *by Jan vom Brocke*
- HCI Research Based on Neurophysiological Data *by Pierre-Majorique Léger*
- Decision Neuroscience on HCI *by Angelika Dimoka*

BRAIN-COMPUTER INTERACTION: A NEW DIRECTION IN HCI

Brain-computer interaction or a brain-computer interface (BCI) provides non-traditional assistance for controlling computers using neural input. It provides users with capabilities for communication and control of environmental, navigational, and prosthetic devices. Research in the field of BCIs spans several disciplines including computer science, electrical engineering, cognitive psychology, neuroscience and information systems, all working to discover the most appropriate alternatives for users with severe motor disabilities and breakthrough devices for use by able-bodied individuals. Brain-computer interaction researchers incorporate brain imaging and signal acquisition techniques long-used in clinical and medical settings to explore the use of BCIs in real world settings and for control. Most applications target disabled users who are cognitively intact but have such severely limited mobility that system input through physical movement (using a keyboard, mouse, joystick, switches, or eye-gaze devices) is infeasible.

There are a number of different types of BCIs available that vary according to the type of electrophysiological signal recorded, method used for recording, and cognitive tasks employed. Some of the most common recording techniques include: EEG for non-invasively recording the electrical activity of the brain, implanted electrodes as an invasive approach to recording electrical activity of the brain, fMRI using a strong magnetic field to measure changes in oxygenated blood volume of the brain, and functional near-infrared (fNIR) imaging using light in the near-infrared spectrum to measure localized changes in oxygenated blood volume in the brain.

Everyone does not experience equal success with controlling a BCI; where someone is able to control a particular BCI technology with great reliability, another cannot control it at all. The match between an individual and technology is an *individual-technology fit* and can be reflected by the individual's performance with the technology. A methodology that explains performance with available brain-computer technologies based on individual characteristics can greatly expedite the technology-fit process, where *characteristics* are a person's demographic, physiological, and cognitive traits (Randolph and Jackson, 2010; Randolph et al., forthcoming; Randolph et al., 2006; Randolph et al., 2005).

Brain-computer interaction improves quality of life for individuals with severe motor disabilities and provides hands-free control for all. However, BCIs requires that users achieve a level of literacy and be able to harness their appropriate electrophysiological responses for effective use of the interface. Further, recording techniques can be time-consuming and resource-intensive to transport, set up, and train; systems often require weeks of training to achieve higher levels of accuracy. A formalized process is still being developed for determining a user's aptitude for control of various BCIs without the need for testing on an actual system. More work is underway to confirm the links between initial controllability, training, and motor skill enhancement where differences in individual characteristics may ultimately be the deciding factor. Lastly, when compared to more traditional devices that are based on direct physical movement, BCIs that record electrophysiological and metabolic signals often have high error rates and low information transfer rates, or bandwidth.

Brain-computer interaction is increasingly being recognized as a special subset of HCI. There are a number of overlapping concepts such as end-user design and usability, a key determinant of BCI effectiveness as with other systems. There have been two recent workshops at the premier international conference on Computer-Human Interaction (CHI): "Brain-Computer Interfaces for HCI and Games" in Florence, Italy in 2008, and "Brain Body and Bytes: Psychophysiological User Interaction" in Atlanta, GA in 2010. Attendees range from entrepreneurs to cognitive neuroscientists. Other relevant conferences where work has repeatedly appeared within the last six years include the International Conference on Human-Computer Interaction (HCII) and the International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS) in addition to the Americas Conference on Information Systems (AMCIS) and the International Conference on Information Systems (ICIS).

NEUROSCIENCE AND DESIGN SCIENCE RESEARCH

Design-oriented research concerns the designing process of IT artifacts, i.e. constructs, models, methods, and instantiations. Dealing with specific types of artifacts, various sub-fields have emerged in IS research, such as onthology engineering, reference modelling, methods engineering, and software engineering (e.g., vom Brocke, 2006). These disciplines have also reached wide interest in practice since their artifacts have often proved useful in providing (generic) solutions for real-life problems.

In design-oriented research, two lines of inquiry, in particular, can be distinguished: Research by Design and Research on Design (vom Brocke, 2010). Table 1 opposes the two approaches to one another, and indicates specific opportunities for NeuroIS that will be illustrated further.

	Research by Design	Research on Design
Approach	Carrying out design and evaluation processes	Reflecting on design and evaluation processes
Statement	Relation between artifact and perceived utility in a given context	Relations between design decisions and the quality of the artifact
Objective	Development of innovative and purposeful artifacts	Acquisition of knowledge about design and evaluation processes
Roles of neuroscientific methods and theories	(1) Evaluation of artifacts (2) Use of theories from neuroscience	(1) Development of new design theories (2) Evaluation of existing design theories

Table 1. Roles of neuroscientific methods and theories in Research by Design and Research on Design (vom Brocke, 2010)

Research by design, as to be seen in design science, aims at designing and evaluating artifacts in an iterative process in order to identify solutions that will prove to be useful in certain types of applications. Here, both the grounding and the evaluation of these solutions is an important quality criterion which neuroscience could substantially help to improve in quality.

First, and probably most obviously, neuroscience can provide new measurement techniques for the evaluation of artifacts. To date, qualitative and quantitative approaches, such as case study research and simulations, are commonly used for the evaluation of artifacts. Neuroscience measurement techniques provide innovative and more objective ways to monitor the actual cognitive effects which artifacts in a certain layout might cause for individual recipients. Apart from fMRI also “light weight” measurement techniques are available, such as GSR, pupil behavior, and heart rate that can be applied at lower cost and in a more authentic scenario.

Second, research by design can also benefit from neuroscientific theories that are already at hand and can well be used in order to inform the design of artifacts. Past PET (positron emission tomography) studies, for example, measured cognitive load, and fMRI was used to identify specific brain regions that are associated with “cognitive conflict”, such as the anterior cingulate cortex (ACC). Such results can be used in order to take into account cognitive effects of artifacts already during the planning phase. Important constructs may include the cognitive load caused by an artifact given a certain information processing capacity (and cognitive style) of the target group.

Regarding *Research on Design*, as to be seen in research on design theories, the study of the design process itself is at the core of design-oriented research. Here, neuroscience can help both to generate new design theories and evaluate existing ones.

As far as new theories are concerned, specific design relations between parameters of information systems design and cognitive effects could be subject to these studies. That way more general findings from neuroscience could be related to typical design issues in information systems, such as the presentation of information in an artifact representation. That being said, not only the representation of artifacts but also the creative processes of artifact design would be a promising field to study in order to learn more about the “art” of good artifact design.

Apart from new theories, also existing theories can benefit form NeuroIS research. Here, the Technology Acceptance Model (TAM) may serve as an example that has recently been revisited making use of neuroscientific theories and methods (Davis and Banker, 2010; Dimoka and Davis, 2008). In the same way further theories, in particular design theories, may well be evaluated given the new opportunities that neuroscience can provide.

HCI RESEARCH BASED ON NEUROPHYSIOLOGICAL DATA

Neurophysiological techniques offer HCI research the opportunity to complement and enrich existing data sets (e.g., based on surveys) with other sources of empirical evidence which were previously hard to collect in a reliable and valid way. Several researchers are currently suggesting the use of neurophysiological measurement tools to seek convergent validity of current psychometric tools (e.g., Dimoka et al., 2010a). The main objective is not to replace the existing validated constructs but to triangulate them with neurophysiological measures.

To measure neurophysiological states in an externally valid way, the IT task that a subject has to perform during a given experiment needs be as authentic and as realistic as possible. The use of neurophysiological approaches, in contrast to neuroscientific techniques such as fMRI (where the subject is lying in a brain scanning machine), helps to create a more normal and more authentic environment for the subject because he or she can sit normally in front of computers (Riedl et al., 2010a). Yet, a subject must believe that the task is real rather than experimental in order to make possible inferences with a high degree of external validity.

Therefore, the challenge for researchers is to create an authentic and realistic corporate IT environment context to ensure the validity of the experimental neuroscience research on end-user interactions. Current research at the ERPsim Lab in Montréal aims at providing a methodological tool called *ERPsim* (Léger, 2007; Léger et al., 2007) that offers the possibility to collect neurophysiological data while the subject is immersed in a realistic interaction with a real life enterprise resource planning (ERP) system (SAP). A subject has to analyze standard reports and make appropriate transactions in the ERP system in order to solve a complex business problem. One can think of ERPsim as a flight simulator for ERP systems where end-users are flying a real corporate information system in a virtual business environment.

During an experiment with ERPsim, neurophysiological data (e.g., electrodermal activity, EDA, or EEG) are collected and can be triangulated against other empirical evidences (e.g., ERP system clickstream and psychometric measures). This makes possible the creation of a rich longitudinal dataset.

ERPsim can contribute to research on ERP-related concepts, using the simulator to gather data that were previously difficult to obtain. One example is an ongoing research project on the notion of cognitive absorption (CA). This concept corresponds to a state of deep involvement with a software program. CA has widely been studied over the last decade in the IT literature using psychometric instruments. Measuring ongoing CA with psychometric tools requires interrupting a subject's ongoing usage behavior to self-evaluate their level of absorption. Such interruptions may alter or contaminate the very CA state the researcher is attempting to measure. To circumvent this problem, this research is investigating the effectiveness of psychophysiological measures in CA. Preliminary results from an ongoing research project are focused on the correlation between electrodermal activity (EDA) and several dimensions of the CA construct such as curiosity and focused immersion (Léger et al., 2010).

The ERPsim Lab is currently working on extending its platform to directly integrate the psychophysiological equipment of a Montréal-based company called Thought Technology Ltd. The objective is to ultimately provide the NeuroIS community with a flexible research tool to conduct experimental researches in complex IT environments, while collecting a rich set of data pertaining to the behaviors and emotions of users while interacting with IT.

DECISION NEUROSCIENCE ON HCI

First, Dimoka will explain that there are corresponding applications of neuroscience to related fields, such as economics (neuroeconomics), psychology (neuro-psychology), and marketing (neuromarketing). Moreover, there is an emerging field of study termed decision neuroscience that specifically focuses on the applications of neuroscience to the social sciences, which explores problems (with the aid of neurophysiological tools) that are related to the domain of IS research, such as decision-making, utility and rewards, learning, emotions, and cognition.

Second, Dimoka will discuss what factors make the choice of fMRI methods particularly beneficial in HCI studies, and how it is possible to tackle research questions that could not be answered with existing methods. For example, merely identifying the neural correlates of IS constructs (which brain areas are activated in response to IS constructs) can be extremely useful in better understanding the nature and dimensionality of IS constructs, offering examples from a study of the neural correlates of the TAM constructs (Dimoka and Davis, 2008). Moreover, comparing brain and behavioral data that correspond to the same IS construct can be particularly insightful, as evidenced by some exciting gender differences across different IS constructs that vary in terms of their underlying cognitive and affective processes (Dimoka, 2010a). Besides, it is possible to identify "hidden" processes that people are either unable, unwilling, or uncomfortable to self-report, such as perceptions about ethnic and gender similarity that people do not truthfully self-report due to social desirability bias and political correctness (Dimoka et al., 2010a). In sum, Dimoka will try to make her point that novel research insights can emerge from neuroIS studies by discussing how brain data can complement existing sources of data to shed light on IS phenomena where existing methods may not offer adequate insights.

Then Dimoka will outline a set of guidelines for conducting an fMRI study and it's applications to HCI. Given the increased interest in using neuroimaging tools in the IS discipline, she will discuss the key steps needed to conduct an a valid fMRI study and ensure that enough detail is provided to evaluate the methods and results. The proposed 'roadmap' for conducting fMRI studies is categorized into (1) formulating appropriate research questions, (2) designing the fMRI protocol, (3) analyzing fMRI data, and (4) presenting and interpreting fMRI results. These guidelines can be useful for IS researchers who are already doing or intending to do fMRI work, reviewers who evaluate the quality of fMRI studies, and people who would like to understand fMRI studies.

Following, Dimoka will discuss some of the difficulties range from becoming familiar with the vast neuroscience literature, accessing neuroimaging facilities, obtaining funding, conducting studies with neuroimaging tools, analyzing psychophysiological and brain imaging data, and presenting truly novel findings. She will also explain that fMRI experiments may not differ substantially from traditional behavioral experiments, offering guidelines on how to use stimuli that closely correspond to those used in traditional behavioral studies, such as psychometric measurement items to induce brain activation for specific IS constructs (Dimoka, 2010b). Moreover, she will provide an overview on how to obtain relevant knowledge about neurophysiological tools through specialized workshops and other learning forums. She will also offer a discussion on the pros and cons of teaming up with neuroscientists and handling the collaboration in terms of managing expectations, obtaining funding, and writing joint publications.

Finally, Dimoka will report on her experiences in reporting NeuroIS results in IS conferences and attempting to publish neuroimaging studies in IS journals, concluding that the novel approach rendered by NeuroIS studies make it possible to propose some exciting new findings that can inform IS research. Hence, despite the widely touted potential of NeuroIS, it is important to recognize, discuss, and attempt to overcome these challenges and potential roadblocks in order to harness the potential of NeuroIS in HCI.

CONCLUSION

Altogether, the panel debate described in this article is intended to stimulate the discussion on the potential of neuroscience for HCI research. In this context, Izak Benbasat recently wrote in a research commentary about the future challenges and directions in HCI research (Benbasat, 2010, p. 18): "I would encourage HCI researchers to partner with neuroscience experts, if and when possible, to utilize fMRI and a host of other neuroscience methods … fMRI studies have the advantage of revealing new variables that influence outcomes as well as identifying the neural correlates of some of the constructs we commonly utilize in HCI research, such as trust or usefulness … The benefit we gained from using fMRI was a better and deeper understanding of why some users adopted or rejected certain types of interfaces."

Considering this statement and published research which has demonstrated the value of neuroscience for HCI-related research questions (e.g., gender differences regarding the neural processing of Internet offers with a varying degree of trustworthiness, Riedl et al., 2010b), we believe that neuroscience will become an important reference discipline for HCI studies in the future.

Notes: The following references primarily refer to articles published by the panelists. A complete list of references which substantiate the statements and claims in this article can be obtained from the panel chair upon request. Moreover, a selection of NeuroIS publications and related articles is available at www.NeuroIS.org.

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