Introduction to the Special Issue on Neuro-Information Science [*EDITORIAL*]

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Introduction

The field of neuroscience has fruitfully contributed to a wide variety of other fields, for example, economics, marketing, and information systems, where the broad adoption and influence of neurophysiological (NP) research tools led to the creation of several new sub-fields, including neuroeconomics (Camerer, Loewenstein, & Prelec, 2005), neuromarketing (Ariely & Berns, 2010), and neuro-information-systems (NeuroIS) (Riedl & Léger, 2016). There is now a growing interest in the use of NP methods in human-information interaction (HII) and interactive information retrieval (IIR) research, reflected, in part, in a series of international workshops and panels (Gwizdka et al., 2013; O'Brien et al., 2015; Gwizdka & Mostafa, 2016; Mostafa & Gwizdka, 2017). This interest has been motivated, at least partially, by researchers who regularly utilize search logs, direct searcher observation, and questionnaires and interviews as data collection methods and are concerned with the limitations of these traditional methods. Experimental data obtained from NP methods is expected to complement the more traditional data sources and, together, contribute to improving and deepening the understanding of HII (Mostafa & Gwizdka, 2016). The deeper understanding offers the potential for the development of new information search models (Moshfeghi & Pollick, 2018). The long-term and primary goal is to create robust and predictive models that go beyond behavioral data (Pirolli, 2009; Moshfeghi & Jose, 2013, Moshfeghi, Triantafillou & Pollick, 2019; Jaccucci et al., 2019 - this issue) and enable the development of neuro-adaptive IIR systems. A secondary and additional goal is to develop new search models that can account for physiological and neurological responses to information stimuli and the influence of cognitive and affective states on users' information behavior. The NP methods of potential usefulness to HII include: functional magnetic resonance imaging (fMRI) (Moshfeghi, Triantafillou & Pollick, 2016), functional near-infrared spectroscopy (fNIRS) (Maior et al., 2015), electroencephalography (EEG), magneto-encephalography (MEG), eye-tracking (esp. pupillometry) (Oliveira et al., 2009; Gwizdka, 2014; Gwizdka, 2018). Early applications of NP methods to HII have resulted in three emerging threads of active research: (1) the investigation of inferring relevance assessment (Ajanki, 2013; Allegretti, et al., 2015; Barral et al., 2016; Buscher, 2012; Frey et al., 2013; Gwizdka, 2013; Gwizdka, 2014; Gwizdka & Zhang, 2015; Gwizdka, 2017; Gwizdka et al., 2017; Gwizdka, 2018; Moshfeghi et al., 2018; Moshfeghi & Jose, 2013; Oliveira et al., 2009; Salojärvi et al., 2005), (2) the investigation of inferring a realization of an information need (IN) (Moshfeghi et al., 2013; 2016; 2019; Moshfeghi & Pollick, 2019 - in this issue) and (3) the study of human responses to search process (Jimenez-Molina et al., 2018; Moshfeghi & Pollick, 2018; Simola et al., 2008; Slanzi et al., 2017; Scharinger et al., 2016; Tran & Fuhr, 2012). Unfortunately, many IIR researchers (and information science scholars more broadly) are largely unaware of the NP methods and how they could fruitfully contribute to the investigation of their research questions. This special issue aims to increase the awareness of NP methods and their applicability to interactive information retrieval and, more generally, information science. We term this new area, where data obtained from NP methods complements the more traditional information studies data sources and allows deepening the understanding of humans engaged in information search and retrieval, *Neuro-Information Science*.

In this Neuro-Information Science special issue

This special issue contains six articles. The articles in this issue showcase the state-of-the-art work in this area and highlight challenges in applying NP methods to HII and IIR research. The papers' topics span from investigating information relevance, and information need to user satisfaction and emotional reactions to health information and to color vs. text. Before presenting the articles, we briefly introduce the NP methods used in them. The first five articles use the core functional neuroimaging techniques related to the brain's neural activity - EEG/ERP and fMRI, whereby the first and third use eye-tracking in addition to EEG. The last article uses techniques related to the peripheral nervous system (eye-tracking and EDA).

Electroencephalography (EEG)

EEG is one of the oldest neuroimaging techniques dating back to the work of German psychiatrist Hans Berger in the late 1920s (Tudor et al., 2005). The human brain is a dense structure weighing about 1.5 kg and containing around 100 billions of neurons (Herculano-Houzel, 2009). Neurons communicate on the average every five milliseconds through electrical impulses and neurotransmitters. EEG directly measures electrical activity associated with the neuronal firing from electrodes placed on the scalp. This technique is widely used because of its ability to provide real-time measurements of brain activity. EEG electrodes are typically placed at predefined locations on the scalp. Although EEG lacks spatial precision to establish specific brain regions where the signals originate from, EEG signal can be associated with neuronal activity in larger brain areas (for example, prefrontal and frontal areas located at the front of the head, occipital area located at the back of the head). EEG signals are often converted from the temporal into the frequency domain. By convention EEG wave frequencies are divided into several frequency bands named after Greek letters: δ (delta) is below 3.5 Hz, θ (theta) is 4–7.5 Hz, α (alpha) is 8–13 Hz, β (beta) is above 13 Hz, and γ (gamma) is used for frequencies above 30–35 Hz (Lopes da Silva, F.H. et al., 2009). Strength of activity in different frequency bands has been associated with different mental or behavioral states. For example, increased activity in the α-band occurs in a state of relaxed wakefulness. In contrast, strongly attenuated α-waves have been associated with the state of alertness (Lopes da Silva, F.H. et al., 2009).

EEG - Event-related potentials ERP

An alternative approach to frequency analysis of EEG signals is to use event-related potentials (ERPs). This approach is based on averaging EEG response waves locked to the event onset (e.g., to the start of a stimulus presentation) across people and trials (Makeig, 2009). The motivation for averaging is to remove unwanted signals effectively and to improve the signal-to-noise ratio in EEG. Many characteristic ERP response waves have been established in relation to a wide variety of perceptual and cognitive phenomena. For example, the P300 wave pattern (a positive signal occurring after about 300 ms from an event onset) is strongly associated with oddball tasks involving detection of low-probability events. In the context of information interaction, the P300 effect is commonly associated with the beginning of conscious attentional processing (Dien, 2009). The N400 wave patterns are prominently associated with processing semantically meaningful stimuli such as words, icons, faces. This wave pattern is typically amplified for reading sentence completions that are semantically unexpected (Dien et al., 2010).

Functional Magnetic Resonance Imaging (fMRI)

Functional magnetic resonance imaging, or fMRI,measures brain activity (Soares et al., 2016) using the Blood Oxygen Level Dependent (BOLD) signal, which is generated by a complex process related to blood flow, blood volume and the ratio of oxygenated blood to deoxygenated blood (Ogawa et al., 1993). The BOLD signal is not a direct measure of the activity of brain cells but can be viewed as a proxy for neural activity. Although the indirect link between neural activity and the BOLD signal limits how fMRI data can be interpreted (Logothetis, 2008) it has become one of the primary tools of cognitive neuroscience since the early 1990s. There are important advantages of fMRI compared to other brain imaging technologies. fMRI has a superior spatial resolution, on the order of millimetres, and can accurately measure activity within the entire brain volume. There are limitations to the use of fMRI. One significant limitation is that participants must typically lie still in a confined space to perform an experiment, and this strictly limits its abilities to measure mental activity during naturalistic behaviour. Another limitation is that the temporal resolution of fMRI is relatively slow, on the order of seconds. It takes around 1-2 seconds to acquire a measurement of the entire brain and the complex way that the BOLD signal is related to neural activity further acts to decrease temporal resolution. Finally, obtaining measurements requires equipment that is expensive to purchase and maintain.

Eye-tracking

Eye-tracking (ET) dates back to the late XIX c. (Duchowski, 2007; Holmqvist. et al. 2011) and is one of the most widely used NP modalities in research. The essential functioning of ET is based on eye-mind link hypothesis, which states that our attention is where our eyes are looking (Just & Carpenter, 1980). The human eye can see with high acuity only a tiny fraction of the surrounding world, approximately 1.5-2 degrees of visual angle, called foveal vision. Outside this small area, our peripheral vision reaches approximately 90 degrees in each direction where the perceived image becomes progressively blurred, enabling us to perceive movement but no details beyond the foveal region. Our visual acuity drops from 100% in foveal view to 25% at around 6-7 degrees of visual angle (Rayner et al., 2011). Therefore, in order to perceive the surrounding world, our eyes need to move all the time, sweeping the world in front of us to capture visual information. Eye movements are a combination of 'events', three of which are of most interest to researchers: fixations (periods when eyes are relatively still), saccades (rapid jumps in-between fixations, during which vision is suppressed) and blinks (Holmqvist et al., 2011). Visual information is acquired only when eyes fixate, and details are captured in the foveal view. Fixations provide us with the information where a user's attention is focused on a screen, or, more generally, in the environment. Eye-trackers detect 'eye-events' by capturing images of reflections from the cornea (the outer part of the eye) and eye pupil and employ geometry to calculate in real-time where each eye is looking. This is done many times per second (from 30 times to over 1000 times per second) producing a record of eye movement with relatively high accuracy.

Pupil dilation

An additional measure typically captured by eye-trackers is pupil diameter. Pupil dilation is controlled by the autonomic nervous system (Onorati et al., 2013). Under constant illumination, dilation has been associated with a number of cognitive functions, including mental workload (Kahneman and Beatty, 1966), interest (Krugman, 1964), surprise, and decision making (Preuschoff et al., 2011). Prior work in information science has demonstrated significant changes in pupil diameter in response to differing levels of information relevance (Gwizdka, 2014; Gwizdka and Zhang, 2015; Gwizdka et al., 2017).

Electrodermal Activity (EDA)

Electrodermal activity (EDA) is one of the earliest tools used in psychological research. It measures changes in electrical conductance of the skin that result from autonomic sympathetic neuronal activity; one type of EDA is galvanic skin response (GSR). GSR is the change in sweat gland activity that reflects emotional arousal. GSR signal includes very slowly changing tonic base-level component (seconds to minutes), and a much faster changing phasic component (seconds) (Critchley, 2002). Both positive (e.g., "joyful") and negative (e.g., "saddening") stimuli can result in increased arousal, which leads to increased skin conductance. The GSR signal, therefore, reflects emotion intensity, but not its type. GSR is sensitive to immediate emotional arousal as well as general mood or acute stress responses. The polygraph (i.e., the lie detector) uses GSR (Brierley-Bowers et al., 2011). GSR is obtained by attaching two leads to the skin (typically to fingers).

The articles

Jacucci et al. (2019) open this special issue with their article titled "Integrating neurophysiologic relevance feedback in intent modeling for information retrieval". A core feature of IIR systems is that the relevance of search results can be improved by gathering either explicit or implicit judgements from the user. Most systems rely on implicit actions, treating the choice to click on a result, for example, as a positive indicator that it was considered relevant by the searcher. However, it is hard to know whether results that were not clicked, for example, were not relevant or not the most relevant, and so on. In this paper, Jacucci et al. consider whether systems can improve the assessment of implicit relevance judgements, by interpreting a person's neurophysiological responses to search results. Their approach can generate relevance feedback in real-time from brain signals (EEG) and eye movements in a realistic scenario. Their work represents the first complete information retrieval system that uses NP signals, thus providing foundations for future work in neuroadaptive information retrieval.

The second article titled "ERP/MMR Algorithm for Classifying Topic-Relevant and Topic-Irrelevant Visual Shots of Documentary Videos" by Kim & Kim (2019) continues the theme of identifying whether a user considers content to be relevant, Kim & Kim focus on evaluating whether viewers consider segments of video as relevant to a topic or not, with the aim of creating accurate, relevant summaries of documentaries. Their classifier uses two specific patterns in Event-Related Potentials (ERPs) in EEG data (N400 and P600) as indicators to make these judgements. They compare this technique against hand constructed ground truth methods, and find that it performs better than depending on algorithms that detect the boundaries of clips automatically (e.g., based on changes in image color histograms). The results suggest that their method may be applied to the mechanical construction of a video skim.

Chen Xu et al. (2019) in the article titled "The dominant factor of Social Tags for users' decision behavior on e-commerce websites: Color or Text" use ERPs and eye-tracking in their work, in order to understand how people unconsciously respond to color during searching and browsing. In the target domain, textual tags are also given colors to indicate whether the user considers the tag to be positive or negative. The study is performed in a culture where red has a positive association for color. Their data from the first study, which uses ERPs, shows that the red colour quickly evokes a positive response. Their second study uses eye-tracking and shows that emotion induced by colors was more influential in high cognitive load condition, whereas the emotion induced in the text was more influential in low cognitive load condition. Their work demonstrates the importance of considering the implications that color choice may have on searchers, especially during high workload tasks.

Moshfeghi & Pollick (2019) in their article titled "Neuropsychological Model of the Realization of Information Need" use fMRI to get insights into neural activities engaged when searchers becomes aware of their information need (Cole, 2011). Information need (IN) is one of the main concepts in information retrieval. Despite decades of seminal work on IN, IR and relevant scientific communities do not still fully understand "how information need occurs?" and "what processes form the basis of its existence?". This is due to the complexity associated with IN, i.e. at the very initial state of it (i.e. at a visceral level), even the searcher may not be aware of its existence, in turn limiting the means to experimentally probe such tacit states of experience. In their paper, Moshfeghi & Pollick (2019) provide a holistic view of the realization of IN using fMRI. To do so, they examined the functional connectivity (Friston, 2011) among the brain regions reported in Moshfeghi, Triantafillou & Pollick (2016). Based on their examination, they present the first of its kind neuropsychological model of the realization of IN. Their model consists of three components: (i) a successful memory retrieval component, (ii) an information flow regulation component, and (iii) a high-level perception component. This model helps to view the fundamental process of Information Need within the context of inter-relating subnetworks that act to realize the different psychological processes subsumed by Information Need. Also, their findings showed a close relationship with neurocognitive studies of Feeling of Knowing (FOK) in metacognition, which reinforces the similarities of IN and FOK at a behavioural level. Moshfeghi & Pollick (2019) study and their neuropsychological model of the realization of IN constitute an essential step in unravelling the nature of information need and will have a significant impact in directing future works into how to better satisfy IN.

The study presented by Jones et al. (2019) in the fifth article titled "The relationships between health information behavior and neural processing in African Americans with prehypertension", also employ fMRI. Health Information Seeking (Cline & Haynes, 2001) is an area of IIR that receives much attention given its high-importance for the searchers - it is often a realistic and easily adoptable work-task that many people can identify with. It is also considered a concerning topic, as the results can have a negative emotional impact on searchers in a way that many work-related IIR tasks do not. To understand how we respond to medical information online, the work by Jones et al. uses knowledge about regions of the brain, relating to analytical and empathetic behaviours, to examine responses to health information online, in particular with prehypertensive users. fMRI scans are used to show that although health information is often presented as objective, the empathetic and social regions of the brain are activated in searchers.

Finally, Wu et al. (2019) in an article titled "Investigating the Role of Eye Movements and Physiological Signals in Search Satisfaction Prediction Using Geometric Analysis". This research represents a theme in the Neuro-Information Science field that observes neuro-physiological responses related to the peripheral nervous system that then are related to established cognitive processes. The authors investigate how eye movement and skin response (electrodermal activity) are affected by satisfaction on information search, as a cognitive process. They confirm that these neuro-physiological signals significantly improve linear models for predicting search satisfaction and that these models successfully generalize across users and tasks. The presence of noise in NP signals is a common challenge faced by researchers. Thus the second goal of this article is to demonstrate one approach to effectively reducing noise by applying a multiscale framework.

Summary

The articles included in this special issue demonstrate the state-of-the-art application of NP methods in information science research. They demonstrate the huge potential for using NP methods and data in the service of information science research questions but also highlight many challenges that remain. One is a lack of theoretical and pragmatic knowledge and expertise in the application of NP methods. Addressing this challenge may require establishing collaborations with cognitive neuroscientists and psychologists. Achieving successful collaborations is a challenge on its own since each discipline has its own culture, goals, and publication criteria, often incompatible with other disciplines. The interdisciplinary authorship of articles in this issue demonstrates that such successful collaborations can be established and be productive in yielding novel research approaches and results. The authors' disciplines range from the familiar to JASIST information science, communication, and computer science, to still familiar psychology, and business, to less often present in JASIST health behavior, biological sciences, nursing, mathematics, philosophy, and neurotechnology. Another challenge is difficulty working with new types of complex and noisy data. Forming interdisciplinary teams is one approach to dealing with new and complex data. A few articles in this issue also show examples of novel approaches to dealing with noise in the data.

The NP methods in information science already have international reach as evidenced by the authorship of the six articles from seven countries spanning three continents (Asia, Europe and North America). We are convinced that Neuro-Information Science will continue to grow and hope that this special issue will contribute to increasing the awareness of NP methods and their applicability to information science.

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