

## ON THE USE OF NEUROPHYSIOLOGICAL TOOLS IN IS RESEARCH: DEVELOPING A RESEARCH AGENDA FOR NEUROIS

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## Appendix A

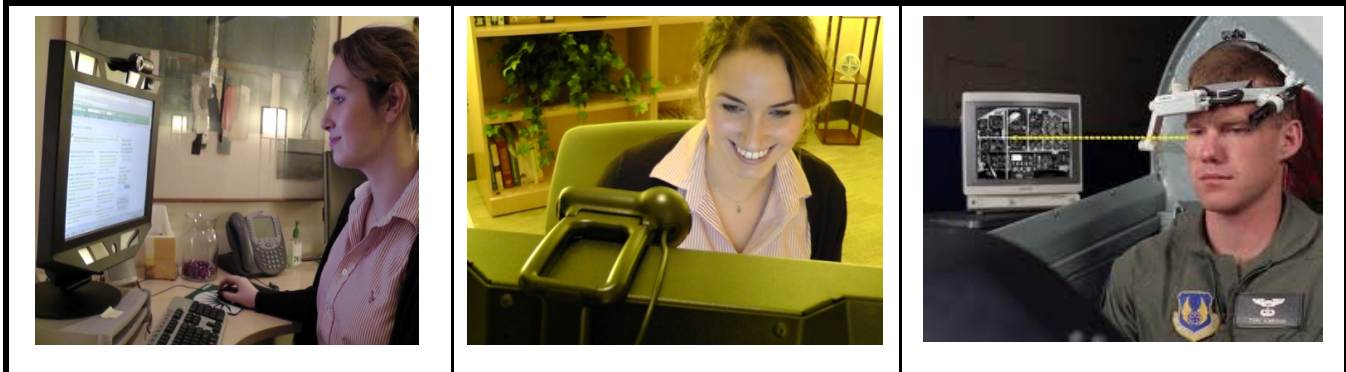
### Description of Neurophysiological Tools

The description of neurophysiological tools is broken down into psychophysiological tools and neurophysiological tools. For additional details, see Riedl et al. (2010).

#### *Description of Psychophysiological Tools*

##### **Eye Tracking**

Eye tracking tools measure where the eye is looking (eye position) or the eye's motion relative to the head (eye movement) (Shimojo et al. 2003). Eye tracking tools gather data on exactly where and for how long subjects focus their eyes on a certain image or stimulus (Cyr et al. 2009).



**Figure A1. Sample Pictures of Eye Tracking Tools**

There are various types of eye tracking devices (Figure A1). Older technologies required subjects to wear a headband with an eye sensor that tracked the eye's pupil while accounting for head movement. More recent devices either use a remote camera mounted on the screen that tracks the pupil's movement (Xu et al. 1998) or use a monitor that tracks what the subject looks at with the aid of infrared sensors (Djamasbi, Siegel, and Tullis 2010a; Djamasbi et al. 2010b). Other eye tracking approaches use a blurred image and a mouse to estimate where the subject looks (Tarasewich and Fillion 2004).

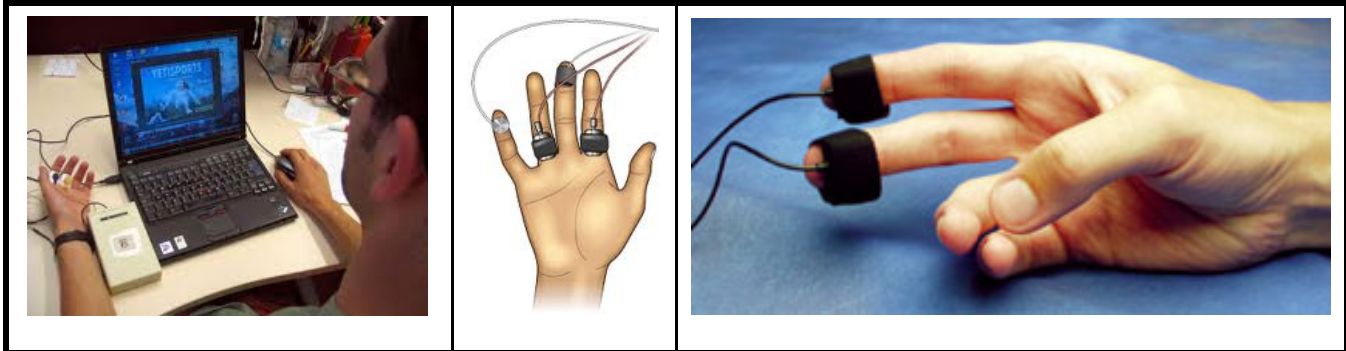
The most important variables obtained by eye tracking tools include eye fixation, pupil dilation, gaze duration, and areas of interest (Rayner 1998). Eye fixation is a spatially motionless gaze (about 2 seconds) on a particular area in a visual display lasting between 100 and 300 milliseconds with a velocity below 100 degrees per second. Pupil dilation gauges a person's interest in the image they are viewing. Area of interest is the region of the display that is specified by the researcher. Gaze duration is the total duration and average spatial location of consecutive eye fixations on a particular area (which ends when the eye fixation moves outside the area of interest). Studies have shown that people tend to have an intense gaze when looking at faces (e.g., Djamasbi et al. 2008). There are additional metrics that can be obtained by eye tracking tools, such as the number or percentage of voluntary/involuntary fixations (Jacob and Karn, 2003). The metrics obtained by eye tracking tools have been linked to cognitive and emotional processes, such as eye fixation to cognitive processing (Pan et al. 2004) and surprising or important areas (Cyr et al. 2009).

Eye tracking has a long history in the social sciences (Rayner, 1998), human-computer interaction (Djamasbi et al. 2008), and computer usability studies (Jacob and Karn 2003). This is because eye tracking is useful for comparing different versions of a computer interface or the effectiveness of different systems. Eye tracking has recently been extended in IS research. For example, Cyr et al. (2009) compared website designs across cultures by examining the area of the website that users focused on. Djamasbi et al. (2010b) showed that users found a page with images of people's faces to be more appealing than a page without images of faces. In their study, users performed their tasks more quickly when there were faces present, resulting in higher trust in the informational content of visually appealing pages.

Eye tracking has several notable advantages that make it a promising tool. Most important, eye tracking can identify human visual activities that cannot be self-reported because subjects cannot perfectly recall what they saw and cannot articulate where they looked and in what order. Besides, eye tracking produces a clear visualization of what and at what time subjects looked when viewing an image, thus allowing researchers to analyze the location and timing of visualization data. However, eye tracking has some disadvantages. First, eye tracking does not capture peripheral vision, which constitutes the majority of human vision, and people look at things without fixating on them. Second, if subjects are aware that they are being observed with an eye tracker, it may bias the natural setting of the experiment. Finally, what subjects saw does not necessarily imply what they paid attention to, what they understood, or the meaning of what they saw.

### **Skin Conductance Response**

Skin conductance response (SCR), also known as electrodermal response (or galvanic skin response), is the phenomenon where the skin temporarily becomes a better electricity conductor when certain external or internal stimuli occur that cause an increase in the activity of human sweat glands (Randolph et al. 2005). SCR tools measure activation in the sympathetic nervous system that changes the sweat levels in the eccrine glands of the palms (or feet or arms). SCR uses electrodes that are commonly placed on the palmar side of the second phalanx of the first and second fingers that send an imperceptibly small electric current through the two electrodes (Jacob and Karn 2003) (Figure A2). The electrodes typically capture a continuous signal that is determined by the subject's sympathetic nervous system (Moore and Dua 2004).



**Figure A2. Sample Pictures of Skin Conductance Response Tools**

SCR has been linked to measures of arousal, excitement, fear, emotion, and attention, and it is believed to be a reliable complement to psychological processes, such as attention and orienting reflexes (Raskin 1973). SCR has been used to study the role of emotions in decision making. For example, Bechara et al. (1999) used the Iowa gambling task to measure decision making as an index of somatic states. In a similar study, Crone et al. (2004) examined the pattern of heart rate (with EKG) and skin conductance (with SCR) that preceded risky choices following the outcomes of bad, moderate, and good performers. Also, van't Wout et al. (2006) used SCR to study emotions in the Ultimatum game,<sup>1</sup> finding that SCR activity was higher when facing unfair offers. This pattern was observed for offers proposed by humans but not computers.

The main advantage of SCR is its very low cost, which makes it widely accessible. Besides, SCR is relatively easy to use and requires minimal intervention on subjects because it is usually placed on the subject's fingers, palms, feet, or arms. However, the main disadvantage of SCR is its lack of predictable measurement, which makes SCR measures potentially unreliable. Moreover, SCR measures are highly subject to habituation effects, which often make repeated SCR measures unreliable. Finally, it is not conclusive what SCR measures represent in terms of the interpretation of SCR output. For these reasons, while SCR was popular in the 1960s and 1970s, it has lost ground to more sophisticated, yet more expensive, techniques, such as fMRI.

## Electrocardiogram

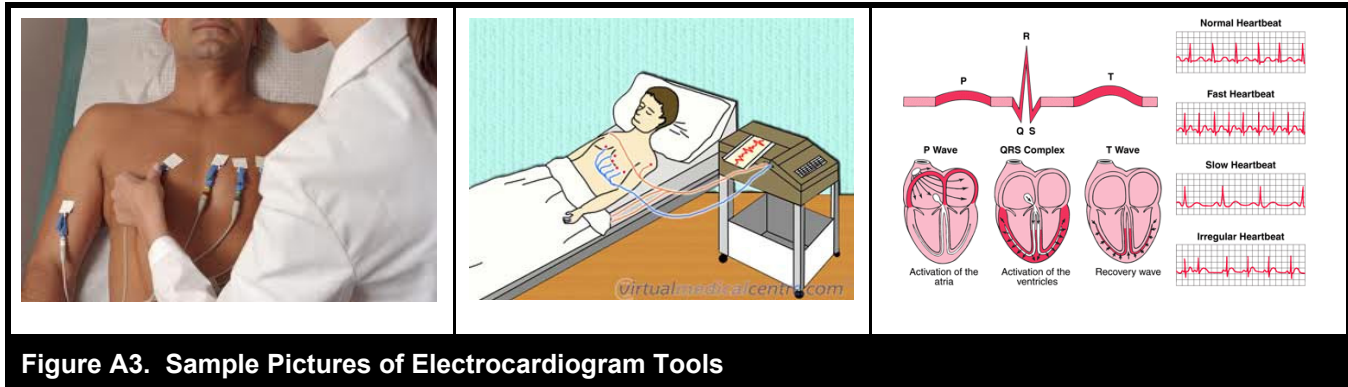
Electrocardiogram (EKG) measures the electrical activity of the heart, specifically how many times the heart beats in a minute. During a heartbeat, an electrical signal spreads from the top to the bottom of the heart and sets the rhythm of the heartbeat. These signals are captured by external skin electrodes that measure the electrical potential generated by the heart (Figure A3).

EKG has been the most commonly used psychophysiological tool, and it is associated with anxiety, stress, effort, and arousal. EKG has also been used to study the role of emotions in decision making. Miu et al. (2008) used EKG while subjects played the Iowa gambling task<sup>2</sup> to capture the heart rate of their emotional responses in order to examine the role of anxiety on decision making. EKG is also associated with anger, which is accompanied by a tonic increase in heart rate. EKG may also be used to capture sadness, which increases blood pressure and decreases cardiac output. Finally, joy may also be captured with EKG.

Similar to SCR, EKG has similar advantages in terms of low cost, wide accessibility, and minimal invasiveness. However, EKG suffers from the interpretation of its findings because heart rate may be affected by a very large set of factors, plus it is virtually impossible to pinpoint which particular feeling (such as anxiety, stress, anger, or joy) triggers the increased or reduced heart rate.

<sup>1</sup>In the single-shot Ultimatum game, the first player offers to divide a sum of money between two players, and the second player has the option to either accept or decline the offer. If the second player accepts, the money is split based on the first player's offer; if the second player declines the offer, neither player receives any money (Güth et al. 1982).

<sup>2</sup>In the Iowa gambling task (Bechara et al. 1994), subjects are given four decks of cards, and they are told that they must choose a card to earn money with the objective of maximizing their earnings. Some cards carry a reward and others a penalty. The game is presented so that some decks are "good" and will earn money, and some are "bad" and will lose money in the long run. Good decision makers learn to pick cards from the good and not from the bad decks.



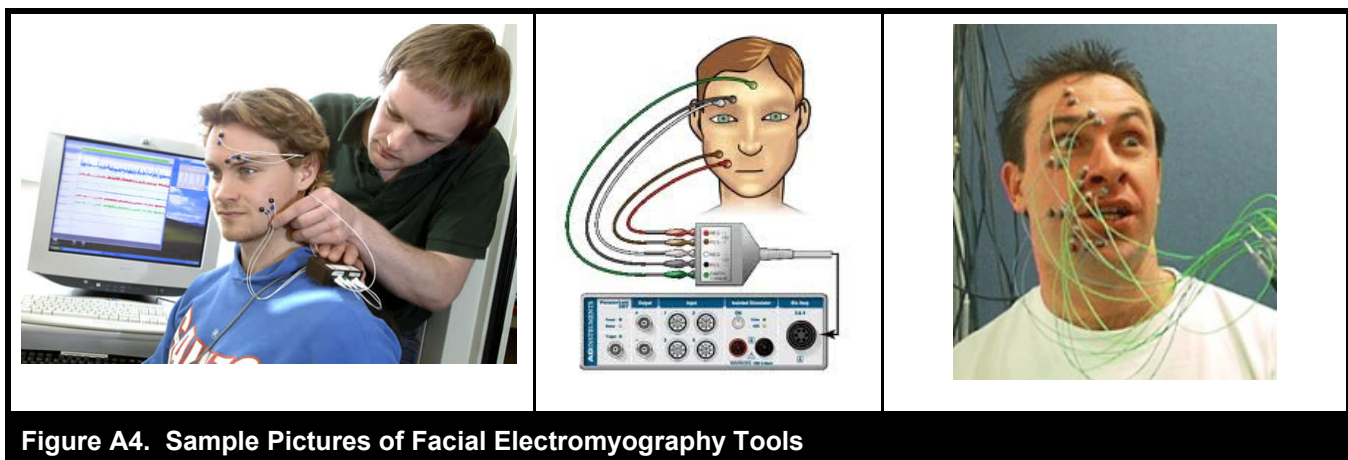
**Figure A3. Sample Pictures of Electrocardiogram Tools**

### Facial Electromyography

Facial electromyography (fEMG) measures muscle activity in the form of electrical impulses spawned by muscle fibers during contraction from two main facial muscles, the corrugator supercilli and zygomaticus. fEMG is measured with small (2 to 4 mm) electrodes placed on the left side of the face (Figure A4), and the raw fEMG signal must be amplified and filtered. Because emotional expression is linked to the contraction of the face, facial muscle activity is linked to emotional reactions (Schwartz et al. 1976), and fEMG offers a direct measure of electrical activity from facial muscle contraction. Studies found that activity in the corrugator muscle (which lowers the eyebrow and is involved in frowning) is correlated with negative emotional stimuli and mood states (such as anger and disgust), while activity in the zygomatic muscle (which controls smiling) is correlated with positive stimuli and mood states (such as pleasure and enjoyment). fEMG can also measure activity at the orbicularis oculi, which captures the magnitude of a blink reflex. Larger blinks are associated with unpleasant stimuli while smaller blinks are associated with pleasant ones.

fEMG was shown to have both better discriminatory power than self-reports in terms of emotional responses and also to be associated with higher recall of commercial ads (Hazlett and Hazlett 1999). Moreover, fEMG was closely linked to real-time emotion-specific events during the advertisements, allowing the authors to conclude that fEMG is superior to self-reports in analyzing commercial ads.

fEMG has several advantages. First, it can measure facial expression with a high degree of precision and sensitivity in a continuous, real-time fashion without any cognitive effort from the subject. Second, fEMG is minimally intrusive. Third, fEMG is relatively inexpensive and widely accessible in behavioral labs. However, fEMG has several limitations. First, fEMG can only get data from a small number of facial muscles because of the limited number of electrodes that can be attached to the subject's face. Second, the quality of the fEMG measures is questionable and there are relatively few fEMG studies in the literature, thus making the interpretation of fEMG measures difficult. Finally, despite being minimally intrusive, fEMG electrodes can still alter natural expression because subjects realize that their facial expressions are being measured.



**Figure A4. Sample Pictures of Facial Electromyography Tools**



## Description of Brain Imaging Tools

### Functional Magnetic Resonance Imaging (fMRI)

fMRI is a noninvasive method that reflects neural activity by measuring changes in blood oxygenation (see Belliveau et al. 1991; Ogawa et al. 1990). Neural activity in a brain area leads to an increase in blood oxygenation, which is referred to as *hemodynamic response*, typically peaking about 4 or 5 seconds after the onset of neural activity. The hemodynamic response, which was shown to be directly linked to neural activity (Logothetis et al. 2001) can be captured with an fMRI scanner (Figure A5) by exploiting the blood's magnetic properties (oxygen-rich versus oxygen-depleted), termed blood oxygen level dependent (BOLD) (Ogawa et al. 1990). fMRI results are often shown with statistical parametric activation maps (SPMs) that contain statistical results of fMRI data computed in a 3D space (voxel or volumetric pixel). As fMRI does not capture absolute levels of blood oxygenation, fMRI results compare the *relative* intensity of BOLD signals across conditions (Friston et al. 1994). Hence, to locate areas of brain activation, a single high-resolution structural image is also acquired. With modern fMRI scanners and protocols (Figure A5), functional images have a spatial resolution of about 2 mm<sup>3</sup> voxels (how closely lines appear on the image). Temporal resolution (how precise the measurement of time is) is only 2 or 3 seconds.<sup>3</sup> Due to the reliable localization of activity deep in the brain with high spatial resolution and adequate temporal resolution, fMRI is now the most commonly used brain imaging tool.

The ability of fMRI to localize brain activity is especially useful for several reasons. First, emotions are associated with areas that are located deep within the brain (see Murphy et al. 2003; Phan et al. 2002). Second, fMRI is non-invasive. Third, because fMRI is widely used, there are standard data-analysis approaches to compare across studies. Nonetheless, fMRI also has some disadvantages (Savoy 2005): First, fMRI has modest temporal resolution (a few seconds). Thus, inferring causal relationships between two brain activities may require complementing fMRI data with the higher temporal resolution EEG or MEG data. Second, fMRI data must be interpreted carefully because correlation does not necessarily infer causation,<sup>4</sup> and brain activity is complex and often nonlocalized (Kenning and Plassmann 2005). Third, there is no consensus about the correct threshold for fMRI statistics yet, so reported results could contain false positives as well as false negatives. Finally, the BOLD signal is an indirect measure of neural activity, and it is thus susceptible to influences by nonneural vascular changes.

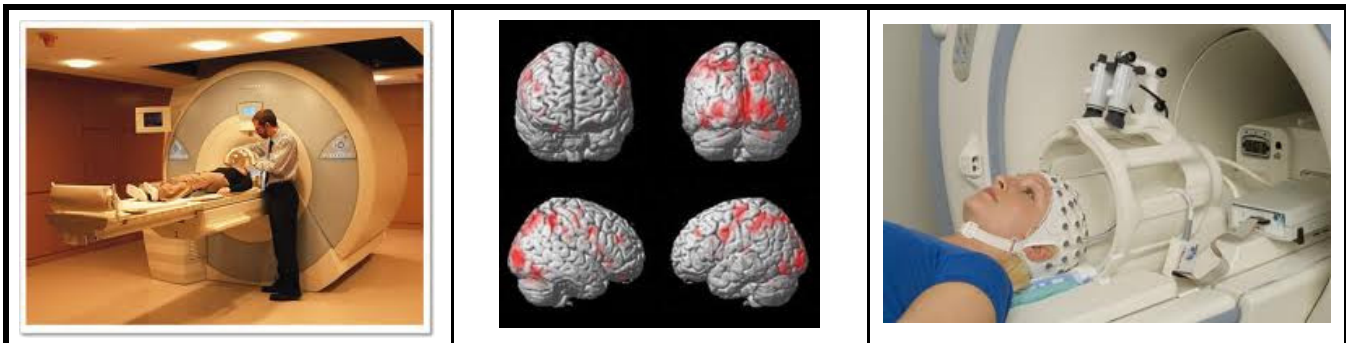


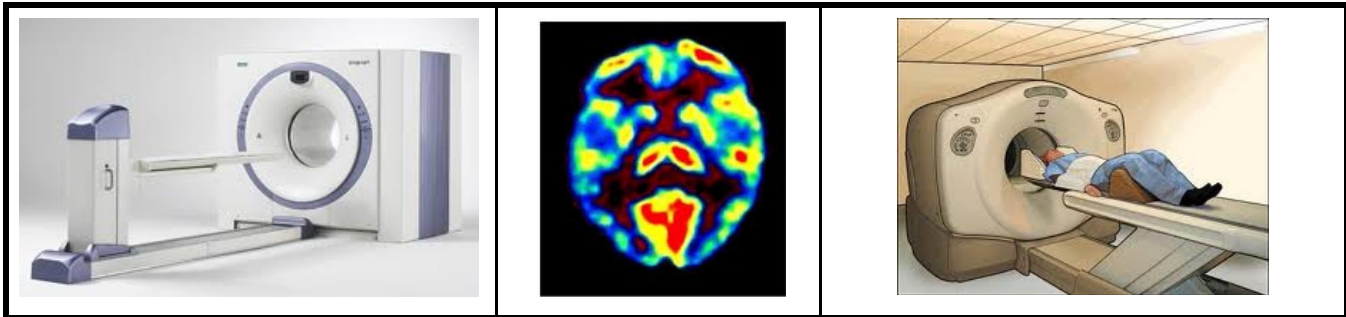
Figure A5. Sample Pictures of fMRI Tools

### Positron Emission Topography (PET)

PET measures metabolic activity by representing neurochemical changes using radioactive tracer isotopes that are detected by a PET scanner (de Quervain et al. 2004) (Figure A6). As radioisotopes decay, they emit a positron; when this positron collides with an electron, a pair of photons (high-energy gamma quants) is produced that travel in opposite directions. PET can detect this pair of simultaneously generated photons and calculate its point of origin from the arrival times. From the distribution of the detected photons, a 3D image is created that represents brain perfusion and metabolism in absolute values (Figure A6).

<sup>3</sup>To be precise, the temporal resolution is not due to the fMRI tool itself but rather due to the hemodynamic response.

<sup>4</sup>To infer causality, fMRI is sometimes used in combination with other tools, such as transcranial magnetic stimulation (TMS), a noninvasive technique. TMS temporarily suppresses specific brain areas, thus creating a “virtual” lesion. TMS helps infer causality by showing that a certain function cannot be performed when a brain area is temporarily disrupted (Miller 2008). TMS and fMRI are sometimes used jointly, because fMRI allows more precise assessment of the impact of the TMS on brain areas connected to the targeted area (see Knoch et al. 2006).



**Figure A6. Sample Pictures of PET Tools**

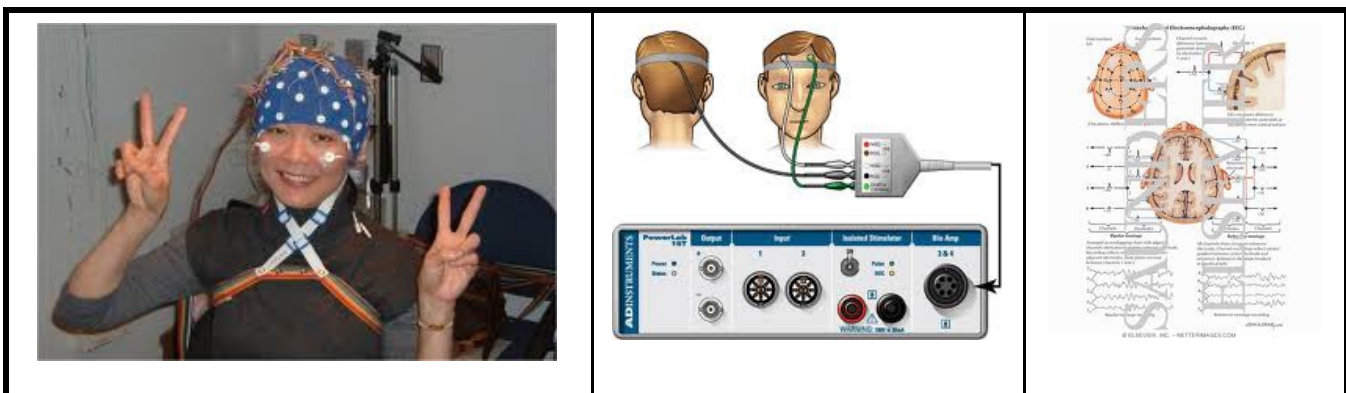
The spatial resolution of PET is similar to fMRI, but its temporal resolution is much lower (2 or 3 minutes). PET costs are also comparable to fMRI. The greatest disadvantage of PET is its invasive and potentially harming nature since subjects have to be intravenously injected with a radioactive tracer. Accordingly, fMRI has generally replaced PET in nonclinical research and PET studies are rapidly declining.

### Electroencephalography (EEG)

EEG measures electrical brain activity from extracellular ionic currents that are caused by dendritic activity. Since the individual electrical potentials are very small, EEG captures the summation of the potentials of millions of neurons that follow a similar spatial orientation. Thus, each electrode captures the summation of the electrical potentials that are generated by millions of neurons (see Lopes da Silva 2004) (Figure A7). EEG typically uses multiple electrodes, often using caps or nets that span the entire scalp (Figure A7).

EEG has several advantages compared to fMRI and PET. First, EEG is cheaper than fMRI and PET, it can be used in many environments (as it is not constrained by the bulky and enclosed fMRI or PET scanners that may cause claustrophobia), it is tolerant to subjects' movements that are not allowed in fMRI, and it is silent (which is important for auditory stimuli). Moreover, EEG has excellent temporal resolution in the order of milliseconds, and is preferred when timing resolution is needed (Kenning and Plassmann 2005). Finally, EEG captures brain activity directly in the form of electrical signals while fMRI and PET use indirect proxies of brain activity, namely blood flow (fMRI) and metabolic activity (PET).

The major limitation of EEG relative to fMRI or PET is spatial resolution. Also, while EEG is sensitive to electrical activity generated in the outer layers of the cortex, it is largely insensitive to electrical activity in deeper brain areas (Mathalon et al. 2003). Thus, compared to designs that are feasible with fMRI or PET, EEG studies require relatively simpler paradigms.



**Figure A7. Sample Pictures of EEG Tools**

However, EEG and fMRI are not mutually exclusive, and it is possible to simultaneously use both tools to take advantage of the high temporal resolution of EEG with the high spatial resolution of fMRI. However, the two data sources may not reflect the exact same brain activity due to different timing; there are also technical difficulties associated with integrating fMRI and EEG data. Nonetheless, there is much research on improving the ability to combine fMRI and EEG data (besides MEG data described below).

### Magnetoencephalography (MEG)

MEG is sensitive to changes in magnetic fields induced by brain activity (Braeutigam et al. 2001). It is based on relatively weak magnetic fields that are induced by synchronized neuronal electrical potentials. Similar to EEG, MEG signals are also derived from the summation of the potentials of ionic currents caused by dendritic neurons. Since the brain's magnetic field is relatively very small (~10 micro Tesla), MEG uses extremely sensitive devices, termed superconducting quantum interference devices (SQUIDS) (Figure A8).

The temporal resolution of MEG is comparable to EEG; however, MEG has lower spatial resolution, and its source localization depends on statistical assumptions. MEG is more effective in registering activity in deeper brain structures than EEG is, but does so at a lower spatial resolution and accuracy than fMRI. This increased spatial resolution compared to EEG comes at increased cost and statistical complexity. Nonetheless, MEG is complementary to EEG, fMRI, and PET.

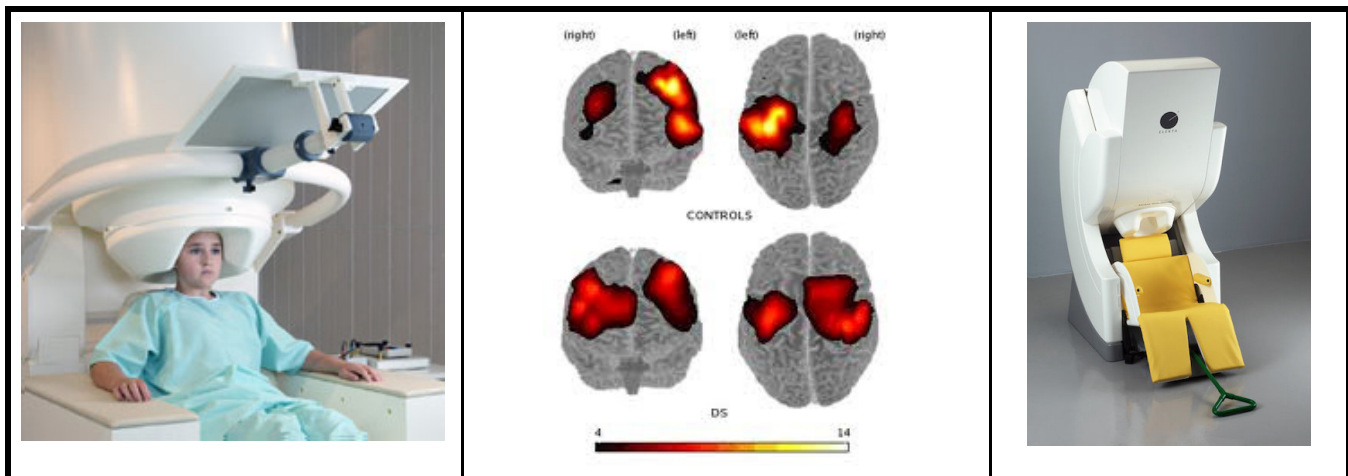


Figure A8. Sample Pictures of MEG Tools

## Cost of Neurophysiological Tools

While the cost of neurophysiological tools is rapidly decreasing, an approximate cost of either acquiring or renting the tools is provided in Table A1. Interested researchers are encouraged to consult with either their own institutions for exact costs for renting the tools or with the commercial companies that sell the tools.

Table A1. Approximate Cost of Neurophysiological Tools		
	Focus of Measurement	Total Cost (US\$)
<b>Psychophysiological Tools</b>		
Eye Tracking	Eye pupil location ("gaze") and movement	~\$10,000 or ~\$100/hour
Skin Conductance Response (SCR)	Sweat in eccrine glands of the palms or feet	~\$2,000 or ~\$25/hour
Facial Electromyography (fEMG)	Electrical impulses caused by muscle fibers	~\$3,000 or ~\$40/hour
Electrocardiogram (EKG)	Electrical activity of the heart on the skin	~\$5,000 or ~\$50/hour
<b>Brain Imaging Tools</b>		
Functional Magnetic Resonance Imaging (fMRI)	Neural activity by changes in blood flow	~\$200-500/hour
Positron Emission Tomography (PET)	Metabolic activity by radioactive isotopes	~\$200-500/hour
Electroencephalography (EEG)	Electrical brain activity on the scalp	~\$100-200/hour
Magnetoencephalography (MEG)	Changes in magnetic fields by brain activity	~\$200-400/hour

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# Appendix B

## Review of Neuroscience Literature

### **Cognitive Neuroscience Theories**

The cognitive neuroscience literature has developed a number of higher-order theories that help explain how human processes guide behavior. In brief, the neuroscience literature has a rich basis of theories for understanding phenomena of potential relevance to the IS literature, and IS researchers may find it useful to review and integrate the neuroscience literature on the particular topic they are examining. This appendix presents some of these theories along with some exemplar studies that have used the theories.

### **Somatic Marker Hypothesis**

The *somatic marker hypothesis* explains how emotional processes influence human decisions and behavior (Damasio 1994). This hypothesis posits that somatic markers (associations about emotional processes), are summed into a single state that facilitates decision making in the presence of various uncertain options. The somatic markers have been associated with the ventromedial prefrontal cortex, and damage to this brain area was shown by an exemplar study by Bechara and Damasio (2005), on affecting decision making.

### **Theory of Mind**

The *theory of mind* is another prominent theory that explains how people infer how others will behave (Fletcher et al. 1995), and the cognitive neuroscience literature linked the anterior paracingulate and medial prefrontal cortex as the brain areas linked to predicting of others' behavior in an exemplar study by McCabe et al. (2001). Related work on mirror neurons (neurons that mirror another person's behavior), was linked to the theory of mind by Iacobini et al. (1999), in terms of imitating the behavior of referent others.

### **Calculative and Emotional Decision Making**

The cognitive neuroscience literature also focused on calculative and emotional decision-making under different conditions (Sanfey et al. 2006), such as balancing rewards and risks (e.g., McClure et al. 2004a), managing uncertainty, risk, and ambiguity (e.g., Huettel et al. 2005; Krain et al. 2006), and assessing various utility trade-offs (e.g., Camerer 2003). The prefrontal cortex (primarily the orbitofrontal and dorsolateral prefrontal cortex), and the limbic system (mostly the anterior cingulate cortex and amygdala), are the two brain areas mostly associated with decision making (e.g., Ernst and Paulus 2005). Moreover, the prefrontal cortex was shown to be responsible primarily for the calculative aspects of decision making, while the limbic system was shown to be responsible for the emotional aspects (e.g., Bechara et al. 1999).

### **Intentions**

There is also a rich literature on various type of intentions as those correspond to planning future behavior (Dove et al. 2008; Petrides 1996), motor intentions (Desmurget and Sirigu 2009), and task-specific intentions (e.g., Haynes et al. 2007; Paus 2001; Winterer et al. 2002). The ventrolateral prefrontal cortex (BA47), is the primary area associated with future intentions by interacting with other brain areas that provide input to the process. Other such areas that contribute to the formation of intentions include the lateral prefrontal cortex that governs motivation (Haynes et al. 2007), and the anterior cingulate cortex that is associated with intentional effort and volition (Paus 2001; Winterer et al. 2002). Motor intentions are quite distinct from cognitive intentions, and they are linked with the parietal and pre-motor cortices (Desmurget and Sirigu 2009).

### **Cognitive Processing**

Cognitive processing is an area that received much attention in the neuroscience literature, focusing on how the brain manages information. The brain can distinguish between cognitive and emotional information (Ferstl et al. 2005); cognitive information is processed in the lateral prefrontal cortex while emotional information is processed in the dorsal frontomedial cortex. Cognitive effort and working memory for short-term information storage and real-time information processing have been linked to the dorsolateral prefrontal cortex (e.g., Braver et al. 1997; Linden et al. 2003; Owen et al. 2005; Rypma and D'Esposito 1999).

## **Brain Localization of Mental Processes**

The neuroscience literature has also focused on the localization of mental activity in the brain or body (termed *neural correlates*), and has created virtual “maps” of the human brain and body by indicating where activity occurs when people engage in various activities. Dimoka et al. (2011), offer an extensive summary of many human processes that are likely to be of interest to IS research, categorized under (1) decision making, (2) cognitive, (3) emotional, and (4) social processes.

In terms of decision-making processes, calculation has been associated with the prefrontal cortex and the anterior cingulate cortex (e.g., Ernst and Paulus 2005; McClure et al. 2004a). Uncertain decision making has been linked to the orbitofrontal and parietal cortex (e.g., Huettel et al. 2005; Krain et al. 2006). Decision-making under different conditions is associated with different brain areas, with risk focusing on the nucleus accumbens (e.g., Knutson et al. 2001; Mohr et al. 2010), uncertainty/ambiguity with the parietal and insular cortices (e.g., Krain et al. 2006), loss with the insular cortex (e.g., Paulus and Frank 2003), and rewards with the caudate nucleus and putamen (e.g., Delgado et al. 2005; McClure et al. 2004a).

In terms of cognitive processes, multitasking is linked to the fronto-polar cortex (e.g., Dreher et al. 2008), and automaticity with the frontal and striatal cortex (e.g., Kubler et al. 2006; Poldrack et al. 2005). Priming (how an earlier stimulus, which is often unconsciously conveyed, affects the response to a later stimulus), is associated with the posterior superior cortex and the middle temporal cortex (e.g., Wible et al. 2006). In addition, habit is associated with the basal ganglia and the medial prefrontal cortex (e.g., Salat et al. 2006), and flow with the dorsal prefrontal and medial parietal cortices (e.g., Iacobini et al. 2004; Katayose 2006). Finally, spatial cognition is linked to the medial temporal lobe and the hippocampus (Shrager et al. 2008).

In terms of emotions, the literature has focused on multiple general and specific emotional processes and their localization in the brain. In terms of the general processing of emotions, the medial prefrontal cortex and anterior cingulate cortex are the two primary brain areas (see Damasio 1996; Phan et al. 2002). Moreover, the literature has focused on specific emotions. Anxiety has been linked to the amygdala and the ventromedial prefrontal cortex (e.g., Bishop 2007; Wager 2006). Disgust is linked to the insular cortex (e.g., Lane et al. 1997), fear to the amygdala (e.g., LeDoux 2003), anger to the lateral orbitofrontal cortex (e.g., Murphy et al. 2003), sadness to the subcallosal cingulate cortex (e.g., Phan et al. 2002), and displeasure to the superior temporal gyrus (e.g., Britton et al. 2006; Casacchia et al. 2009). Furthermore, pleasure/enjoyment has been associated with the nucleus accumbens, anterior cingulate cortex, and putamen (e.g., McLean et al. 2009; Sabatinelli et al. 2007), and happiness with the basal ganglia and ventral striatum (e.g., Murphy et al. 2003, Phan et al. 2002).

In terms of social processes, besides the general theory of mind (McCabe et al. 2001), the literature has focused on specific social issues, such as social cognition (which is associated with the temporal lobe) (Adolphs 1999; 2001), and moral judgment (which is associated with the frontopolar cortex and the posterior superior temporal sulcus) (Borg et al. 2006; Moll et al. 2005). More specific social processes include trust (that is linked to the caudate nucleus, putamen, and anterior paracingulate cortex) (Dimoka 2010; Winston et al. 2002), distrust (which is linked to the amygdala and insular cortex) (Dimoka 2010; Winston et al. 2002), cooperation (which is linked to the orbitofrontal cortex) (Rilling et al. 2002), and competition (which is linked to the inferior parietal and medial prefrontal cortices) (Decety et al. 2004).

In addition to the specific neural correlates associated with these mental processes, there are numerous other processes whose neural correlates have been examined in the vast neuroscience literature. Nonetheless, the neural correlates of these processes could be a good starting point for IS researchers to learn what has already been done in the neuroscience literature, what is already known about these mental processes, whether extant knowledge from the cognitive neuroscience literature can help derive testable hypotheses, and whether new empirical studies are needed in the IS literature.

## **Review of Neuroscience Literature in the Social Sciences**

The ability to link brain functionality to mental processes has captivated the interest of social scientists. Psychologists and economists were the early pioneers of social neuroscience followed by marketers, and many interesting findings have been found by identifying the neural correlates of human behavior, decision making, and underlying cognitive, emotional, and social processes in these disciplines.

In neuroeconomics (the use of neuroscience theories and tools to inform economic behavior), several well-established economic models have been challenged and refined by looking into the mental processes that underlie economic decision-making and behavior (e.g., Camerer et al. 2004; Rustichini 2005). Notably, Smith et al. (2002), challenged a well-accepted economic assumption that payoffs and outcomes are independent by showing that a person’s attitudes about economic payoffs and beliefs on the expected outcomes of these payoffs interact with each other both behaviorally and also neurally. Bhatt and Camerer (2005), challenged another well-established economic theory that effective decision-

making should be governed by rational cognitive processes without relying on emotions. The authors showed that subjects who had good cooperation between the brain's calculative decision-making area (prefrontal cortex), and the emotional decision-making area (limbic system), were the best performers in economic games. Also, neuroeconomic studies were able to explain and refine existing economic theories. For example, prospect theory (Kahneman and Tversky 1979), which theorizes that gains and losses are viewed differently, was explained by neuroimaging tools that showed that one brain area, associated with utility and rewards (ventral striatum), is activated in the prospect of an economic gain while a different brain area, associated with losses (insular cortex), is activated in the prospect of economic loss (Kuhnen and Knutson 2005). This study confirmed that different brain areas govern gains and losses, validating the basic tenets of prospect theory. Moreover, neuroimaging tools were able to explain why people are generally comfortable with uncertain gambles (with specific probabilities for specific gains), but despise ambiguous gambles (without specific probabilities and gains). Hsu and Camerer (2004), showed that the insular cortex (which is activated by intense negative emotions, such as fear and disgust), is activated when decision makers are presented with ambiguous gambles. However, the insular cortex was not activated by uncertain gambles, helping explain why people avoid ambiguous investments.

Neuromarketing (the use of neuroscience theories and tools to inform marketing), has also made major advances in understanding how consumers respond to marketing and advertising (Ariely and Berns 2010; Kenning et al. 2007; Lee et al. 2007; Zaltman 2003). In terms of how consumers make purchasing decisions, Braeutigam et al. (2004), explained the neurological basis of predictable versus unpredictable purchases and linked them to immediate and delayed rewards that are associated with different brain areas. Predictable and impulse purchases are governed by different neurological processes, thus explaining why consumers radically differ in how they make predictable and impulse purchasing decisions. Similarly, McClure et al. (2004a), showed that immediate and delayed rewards (impulse versus planned purchases), activate different brain areas that are associated with inter-temporal tradeoffs. In terms of how consumers react to marketers' branding efforts, Deppe et al. (2005), showed that a consumer's preferred brand choice is responsible for reduced activation in brain areas associated with reasoning and calculation and increased activation in areas associated with emotions and self-reflections, helping explain why marketers invest in brand building to reduce consumers' rational calculation when deciding across competing brands. In a well-publicized Coke versus Pepsi fMRI study, McClure et al. (2004b), explained that people prefer Coke because of brand recognition (by differentially activating the dorsolateral prefrontal cortex that governs cognitive information processing), over Pepsi in a non-blind tasting. However, similar brain areas, mostly associated with pleasant emotions, were activated for both refreshments in blind tasting. These findings explained that consumers prefer Coke over Pepsi due to brand recognition and not taste preference.

In addition to these findings in each discipline, Glimcher and Rustichini (2004), argue that psychology, economics, and marketing are converging under the umbrella of the neuroscience literature to provide a unified theory of human behavior. Therefore, we expect neurophysiological studies to increasingly inform transdisciplinary phenomena in the social sciences that span these core disciplines.

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# Appendix C

## Moderating Role of Culture, Gender, and Age in NeuroIS

Many of the topics discussed in the proposed NeuroIS research agenda could further benefit by the use of neurophysiological tools by inferring neural and psychological differences in individuals, groups, and organizations depending on differences in (1) culture, (2) gender, and (2) age, as elaborated below.

### **Cultural Differences**

A set of proposed research opportunities for understanding cultural differences with neurophysiological tools are summarized in Table C1 and are elaborated in detail below.

First, neurophysiological tools could help identify neural or physiological differences across cultures. This is a prime topic where neurophysiological tools could be particularly useful because culture is a sensitive topic that is often biased by social desirability bias or political correctness. Neurophysiological data that may be more immune from subjectivity bias may be what is needed to push IS research on culture forward.

Second, neurophysiological tools may help compare how people across cultures respond to various designs. The neuroscience has broadly examined cultural differences (e.g., Gutchess et al. 2006; Zhu et al. 2007). For example, Sabbagh et al. (2006), identified significant differences in the brain's executive functioning of small children in a cross-cultural study in the United States and China. In contrast, the authors did not find differences in the brain areas related to the theory of mind, implying that American and Chinese children do not differ in the way they predict how others will behave. Similarly, IS research has extensively studied cultural differences; for example, Cyr et al. (2009), used a combination of methods (including eye tracking), to study how images and website designs are viewed by culturally diverse users. In addition, Cyr et al. (2010), showed that website color appeal differentially affects trust and satisfaction across different cultures. Also, Cyr (2008), and Cyr and Trevor-Smith (2004), found significant cultural differences in how people interact with websites. Building upon these neural differences and similarities in culture, IS researchers can examine how various IT designs are viewed across cultures using neurophysiological tools. Neuroimaging tools, such as fMRI, could help identify neural differences in the visual designs across websites, such as images and color, across cultures. Physiological tools, such as eye tracking, can track how culturally diverse users gaze or fixate on various visual designs, colors, images, and other information on websites, and accordingly prescribe how to structure website designs to cater to different cultures in terms of the overall visual design.

Third, neurophysiological tools may help explore cultural differences in terms of communication, language, and training. Despite the extensive study of communication in IS research and strong cross-cultural effects on IT adoption (Gefen and Straub 1997; Sia et al. 2009), until now, answering what exactly is behind these communication differences has been elusive. It could also have been due to differences in education and socialization across cultures (Hofstede 1980); however, existing tools could not tease out the exact reason, and neurophysiological tools can delve deeper into the underlying origins of such cultural differences. Neurophysiological tools, for example, could focus on potential differences in patterns of brain activation when people from different cultures engage in oral or written communication. How oral or written language makes a difference in terms of how people communicate could also be examined with neurophysiological tools that could capture potential differences in brain or physiological responses during communication. Being able to stipulate the brain area and functionality opens new opportunities to answer such questions. Physiological tools could also explore differences in how culturally diverse people communicate and use language. Such studies could also contribute to the neuroscience literature by answering the call to study culturally shaped factors, such as moral values, social norms, and utilitarian beliefs (Moll et al. 2005). Finally, IT training could be used to influence such cultural differences by either trying to eliminate or exacerbate them, and neurophysiological tools could test whether and how IT training has its desired goals.

Finally, cultural factors may play a role in the design of trust-enhancing IT designs (e.g., Sia et al. 2009). Neurophysiological tools could help examine the neurological and physiological aspects of trust building across cultures to shed light on potential differences on how culture affects trust formation. For example, fMRI can compare whether the neural correlates of various dimensions of trust (Section 3.3.3), are activated differently in these brain areas using the same trust-building stimuli across cultures, and how dissimilar trust-building stimuli have differential effects on the various dimensions of trust across different cultures.

<b>Table C1. Sample Research Opportunities in Understanding Cultural Differences</b>	
<b>Application</b>	<b>Sample Research Opportunities</b>
Cultural Differences	<ol style="list-style-type: none"> <li>1. Examining neural and physiological differences across cultures</li> <li>2. Comparing how people across cultures respond to different IT designs</li> <li>3. Exploring cultural differences in communication, language, and training</li> <li>4. Examining how culture plays a role in the design of trust-building systems</li> </ol>

<b>Table C2. Sample Research Opportunities in Understanding Gender Differences</b>	
<b>Application</b>	<b>Sample Research Opportunities</b>
Gender Differences	<ol style="list-style-type: none"> <li>1. Testing whether gender differences are primarily due to nature or nurture</li> <li>2. Explaining observed behavioral differences across genders in terms of their neurological or physiological origin</li> <li>3. Exploring communication, language, training differences across genders</li> <li>4. Identifying gender differences in emotional and social aspects of websites</li> </ol>

### **Gender Differences**

A set of sample research opportunities for understanding gender differences with neurophysiological tools are summarized in Table C2, as we elaborate in detail below.

Neurophysiological tools could be useful to study gender differences because gender is also a sensitive topic that is often subject to social desirability bias and political correctness. While we propose to examine various gender differences, it is important to note that our discussion is not restricted to biological gender (whether a person is generally regarded as a woman or a man based on genetic or hormonal characteristics). While gender differences are thought to revolve around biological differences between men and women, gender also differs in terms of socialization and experience (sociocultural gender) (Lueptow et al. 1995). Gender is a complex sociocultural construct that distinguishes social relationships among women and men (Santos et al. 2006), and it is the outcome of historic and cultural processes that have developed through sociocultural values about the respective roles of the two biological genders that affect their orientation in terms of masculinity and femininity. This sociocultural distinction is not trivial. Santos et al. (2006), found that sociocultural gender (but not biological), differences explained differences in math ability. Moreover, Cyr et al. (2009), found that sociocultural gender values were a more salient moderator of an expanded technology adoption model than biological gender. Nonetheless, there are also biological gender differences in technology use (e.g., Gefen and Straub 1997; Gefen and Ridings 2005; Venkatesh and Morris 2000). Accordingly, Trauth (2002), argues for a social construction theory to understand the complex nature and effects of gender by focusing on the social shaping of gender with IT. Given these two aspects of gender, our proposed opportunities could apply to both biological gender and sociocultural gender.

First, neurophysiological tools could help identify brain or physiological differences or similarities across biological or sociocultural gender, thus shedding light on the distinction between the two views on gender and to what extent biological gender affects sociocultural gender. For example, sociolinguists have shown that men and women communicate differently (e.g., Tannen 1994), probably due to both nature (biological gender), and nurture (sociocultural gender). Also, it is a well-established fact that the male brain is larger than the female one, even when corrections are made for body size (Rushton and Ankney 1996). However, this male “advantage” in brain size does not imply a male predominance in cognitive ability. Rather, men are better than women in visual spatial imagery (e.g., rotating objects, mathematical reasoning), (Kimura 1992), while women are better in others (e.g., recall of words, color vision) (Gregory 1998). Santos et al. (2006), showed that the traditional argument for mathematical superiority in men is not biological but sociocultural, driven by differences in masculinity and femininity with both boys and girls, with masculine traits performing better. Differences in cognitive ability are also likely to be a function of biological traits (genetics, hormones, brain anatomy), and of socialization, cultural values, and social norms (Cahill 2006). Therefore, neurophysiological tools could help identify whether observed neurological or physiological differences can be attributed to biological/anatomical or sociocultural gender, thus helping better understand the relationship between anatomy/biology and socialization in gender.

Second, Riedl et al. (2010), showed neural differences between men and women (biological gender), when viewing different offers from eBay sellers, implying that, at least partly, the observed behavioral differences across biological gender have their origins in neurophysiological differences. Alternative explanations range from the role of hormones and different brain structures across anatomical gender (Brizendine

2006). Neurophysiological tools may test the wide-held assumption in the sociolinguistics literature that men communicate with social power in mind while women communicate with empathy (Kilbourne and Weeks 1997), thus helping resolve the question of whether it is a matter of preexisting brain structures and hormones or socialization that causes the observed behavioral gender differences.

Third, similar to cultural differences, there are also opportunities for examining how gender differences play a role in communication and use of language (Gefen and Straub 1997), socialization in virtual communities (Gefen and Ridings 2005), and IT training (Venkatesh and Morris 2000). For example, neurophysiological tools could examine differences in communication, language, and socialization across biological and sociocultural gender, thus helping to explain observed behavioral differences in how women and men participate in social communities, how they communicate with others, and how they use written and oral language. Moreover, neurophysiological tools may explore the extent to which IT training differentially affects men and women, thus designing IT systems that will have distinct training patterns for men and for women.

Fourth, Dimoka (2010), found that emotional responses in the brain (amygdala and insular cortex), are more salient in women than men (biological gender). Women also tend to show different preferences in terms of images and colors in websites (Cyr and Bonanni 2005; Moss et al. 2006), differences that attribute to women being more sympathetic to websites with hedonic artifacts and interested in commercial websites that enable socialization (Van Slyke et al. 2002). Rodgers and Harris (2003), noted that lack of hedonic artifacts and socialization may be the reasons that women are less involved in commercial websites. Cyr et al. (2007), found enjoyment to have a significant impact on e-loyalty for women but not men, while social presence was found to have a significant effect on e-loyalty for women but not men. Moreover, Benbasat et al. (2010), showed substantial neurological differences in terms of how women and men perceive social presence in the context of online recommendation agents. In contrast, however, Djasmasbi et al. (2007), did not find differences in terms of how women and men recognize specific IT artifacts on websites. In sum, there are many observed behavioral differences and similarities across gender that cannot be fully explained by existing research tools, and neurophysiological tools can delve deeper into the neurological and psychophysiological underpinnings of these differences, thus trying to better understand the origins of gender differences.

### Age Differences

A set of sample research opportunities for understanding age differences with neurophysiological tools are summarized in Table C3, and we elaborate on these opportunities in detail below.

Age is another potential moderator that could play an important role in the proposed research agenda using neurophysiological tools (Appendix A). While age is also a sensitive issue, we do not expect biases due to social desirability or political correctness, but rather physiological, neurological, and biological differences across people of different age groups. There are physiological differences between younger individuals, normal healthy adults, and ageing adults, such as differences in heart rate (that may affect EKG responses), reflexes (that may affect eye tracking responses), skin conductance (that may affect SCR responses), and muscle flexibility (that may affect fEMG responses). There are also neurological differences across age groups. For example, there are differences in the fMRI signal associated with ageing, specifically that the time lag of fMRI activation is prolonged with increased ageing (Taoka et al. 1998). Moreover, the mechanisms that underlie the fMRI signal were shown to be altered with ageing, making the interpretation of fMRI signals for older people more difficult (D’Esposito et al. 2003). There is also evidence that EEG signals also change with age (Gaudreau et al. 2001). In summary, several of the responses obtained by the proposed neurophysiological tools could be moderated by age (e.g., Buckner 2004), thus creating opportunities for contrasting the various physiological and neuroimaging responses across populations that vary in age.

<b>Table C3. Sample Research Opportunities in Understanding Age Differences</b>	
<b>Application</b>	<b>Sample Research Opportunities</b>
Age Differences	<ol style="list-style-type: none"> <li>1. Studying differences in technology adoption and use across age groups</li> <li>2. Examining the reduction of cognitive overload among older adults</li> <li>3. Exploring differences in strategic decision-making in organizational settings</li> <li>4. Responding to organizational incentives regarding monetary and status rewards</li> <li>5. Designing collaborative tools to enhance group decision-making across age groups</li> </ol>

In terms of individual adoption and use, for example, NeuroIS studies could examine how age may affect the nature and determinants of the adoption and use of systems by examining the neural correlates and physiological responses of people across age groups. Such studies could focus on “hidden” processes that users are unlikely to easily or willingly self-report, such as emotions and habits. Also, usability may vary across age groups, and neurophysiological data can identify direct usability criteria for different ages. Besides, instrumental and hedonic systems may be adopted and used differently across age groups, and neurophysiological studies can complement existing IS studies with direct neural and physiological data. Information and cognitive overload is also likely to differ across age groups, and it may be especially salient among older adults. Thus, the proposed research opportunities on cognitive and information overload may be studied across populations of different ages with emphasis on older adults who may be of greater need for IT solutions to help them overcome information and cognitive overload.

In terms of information systems strategy, managerial decision making could also differ across age groups in terms of relying on cognitive and emotional markers to make decisions. Also, organizational incentives could work differently for different age groups, and differences in the functionality of the human body could be useful in designing appropriate incentives. Promoting cooperation between IT and business functions could also be moderated by age, and neurophysiological tools could assist with the coordination of actions and goals among IT and business people who may be similar or different in terms of their age. Age could also be included as a moderator in studies devising fair organizational arrangements for sharing technology costs and designing fair incentives. This is because people of different ages may react differently to material versus status rewards, and various neurophysiological tools could capture such differences in terms of how people of different ages process incentives physiologically and neutrally.

In terms of group work and decision support, age could also play a moderating role in terms of enhancing online group collaboration and decision support. For example, collaborative tools could be designed differently for groups that differ in their age composition to prevent group members from deliberately discounting and not internalizing information from others. Dual-task interference could be different across age groups, and neurophysiological tools could be designed to help group members of different ages process interventions, enable group members to dedicate their full attention to primary tasks, prevent in-group competition, and avoid negative emotional responses that harm group decision making. Decision aids can also be designed differently for people of different age groups and specifically study how decision aids can create rapport with consumers of different ages to enable interaction with them and truthful responses to sensitive questions, enhancing their decision making. Finally, designing trust-building systems that seek to activate the neural or physiological correlates of trust could be designed differently for people of different ages who may have different bases for trust. In sum, age could be a key moderator in neurophysiological studies related to group work and decision support.

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