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Guidelines for Neuroscience Studies in Information Systems Research

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Guidelines for Neuroscience Studies in Information Systems Research

Abstract. Neuroscience provides a new lens through which to study information systems. These studies, called NeuroIS studies, investigate the neuro-physiological effects related to the design, use, and impact of information systems. A major advantage of this new methodology is its ability to examine human behavior at the underlying neuro-physiological level, which was not possible before, and to reduce self-reporting bias in behavior research. Previous studies that have revisited important IS concepts like trust and distrust have challenged and extended our knowledge. An increasing number of neuroscience studies in IS have given researchers, editors, reviewers, and readers new challenges in terms of determining what makes a good NeuroIS study. While earlier papers focused on how to apply specific methods (e.g., fMRI, functional magnetic resonance imaging), this paper takes an IS perspective in deriving six phases for conducting NeuroIS research and offers five guidelines for planning and evaluating NeuroIS studies: to advance IS research, to apply the standards of neuroscience, to justify the choice of a neuroscience strategy of inquiry, to map IS concepts to bio-data, and to relate the experimental setting to IS-authentic situations. The guidelines provide guidance for authors, reviewers and readers of NeuroIS studies, and, thus, help to capitalize on the potential of neuroscience in IS research.

Keywords: NeuroIS, Neuroscience, Research Methods, Guidelines

Introduction

Neuro-information systems (NeuroIS) research, an increasingly important area in information systems, follows the concept of “applying cognitive neuroscience theories, methods, and tools in Information Systems (IS) research” [10]. According to Riedl et al. [33], 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).“

NeuroIS provides a new lens through which to investigate IS-related phenomena by measuring neuro-physiological effects related to information systems use. NeuroIS studies have provided insights that were once impossible to explore for behavioral research in IS. Using data from the human body, researchers can directly measure the effects that underlie human behavior, particularly affective and subconscious effects. For instance, Dimoka [9] reinvestigates “trust” and “distrust” concepts in IS regarding correlated brain areas and shows that trust and distrust are associated with separate brain areas—trust with the striatum and distrust with the amygdala and the insula. This finding challenges previous understanding of trust and distrust as two occurrences of one construct and suggests that they are two distinct constructs. In addition, Riedl et al. [34] found in their fMRI experiment that most of the brain areas that encode trustworthiness differ between women and men, and that women activated more brain areas than did men, confirming the empathizing–systemizing theory, which predicts gender differences in neural information processing modes. In addition, they suggest studying whether trust has both a cognitive and an emotional component since fMRI studies have shown that some brain regions are associated with cognitive (prefrontal cortex) decisions, while others are associated with emotional (limbic system) decisions. Research in neuroscience has built extensive knowledge about the brain areas and chemical markers associated with such constructs (e.g.,[2, 18, 24, 47]).

Biological systems other than the brain, such as the autonomic and somatic nervous systems, the face, and the eyes, are also included in NeuroIS. In addition to brain imaging, psycho-physiological tools like skin conductance response, eye tracking, face recognition, and heart rate measurement have been applied in NeuroIS studies. Dimoka et al. [10] and Riedl et al. [33] provide an overview of and an introduction to these tools. The wider spectrum of tools allows researchers to choose the most appropriate one with regard to factors like applicability, cost, accessibility, and knowledge required [45].

A few articles provide overviews of theories and tools and discuss the potential of NeuroIS and directives for future research [10, 33, 45, 46], and a growing number of empirical NeuroIS papers (see: www.NeuroIS.org) have raised the importance of establishing knowledge about how to conduct and evaluate NeuroIS research. Scholars who are planning to undertake NeuroIS studies must be able to plan and execute their projects and to interpret the results properly, while reviewers must be able to evaluate the quality of the studies, and readers must be able to understand the study's validity and appreciate its contribution. Clearly, NeuroIS studies must be both relevant and rigorous; the novelty of NeuroIS research does not excuse methodological flaws, nor does it justify publishing studies that make only marginal contributions to the IS field.

The purpose of this paper is to provide a set of useful guidelines, derived from guest-editing this special issue, for those who are involved in conducting, evaluating, and understanding NeuroIS research. Although several papers about NeuroIS in general and fMRI in specific are already published, we need a set of higher-level normative guidelines for high-quality research because NeuroIS includes diverse types of theories and tools for which various normative statements apply. At the same time, these theories and tools are subject to extensive research in neuroscience, so normative advice on this level can and should be drawn from the original work in neuroscience. However, from an IS perspective, it is important to focus the guidelines on the overall research design—how we ensure that our work in NeuroIS contributes to IS theory, and how we document our work in a way that it is convincing to readers and reviewers.

In this paper we propose guidelines for neuroscience studies that take an IS perspective. We abstract from neuroscience theories and tools but focus on guidelines for applying such theories and tools that will help ensure that contributions are made to IS research. We build on prior work in the field of NeuroIS and consolidate knowledge on how to conduct NeuroIS studies in order to develop a frame of reference for researchers, reviewers, and readers with which to evaluate the quality of work in the new field of NeuroIS.

The remainder of this paper is structured as follows. The next section conceptualizes NeuroIS studies as a strategy of inquiry in IS research, develops a framework that illustrates the major phases of a NeuroIS study, and presents five guidelines derived from the framework. Next, we exemplify the guidelines by means of the six NeuroIS studies published in this special *JMIS* issue on NeuroIS in order to illustrate the applicability and contribution of the guidelines. Finally, we discuss the paper's implications and limitations and conclude with a brief summary and outlook.

Neuroscience as a Strategy of Inquiry in Information Systems Research

Neuroscience provides a new strategy of inquiry for IS research: to gain knowledge through the collection of data from people's biological systems using neurobiological tools and theories. Studies in this field are a focused subset of IS studies, and they must contribute to IS theory or practice by accumulating knowledge on the "development, use, and impact of information technologies" [4]. This basic definition provides a boundary of NeuroIS research.

Compared to other data-collection strategies, the neuroscience approach enables researchers to measure bio-data that indicate an individual's emotional and affective state. These signals, physiological reactions of the human body to stimuli, make it possible to capture the subconscious events that may underlie cognition and behavior. We also conceptualize NeuroIS studies as experimental research, that is, research in which one or more variables are manipulated and changes in other variables are controlled and measured in order to test hypotheses.

Against this background, we characterize NeuroIS studies along six essential phases (Figure 1), organized according two dimensions: the phase's positioning according to the progression of research and it's positioning according to its primary disciplinary focus.

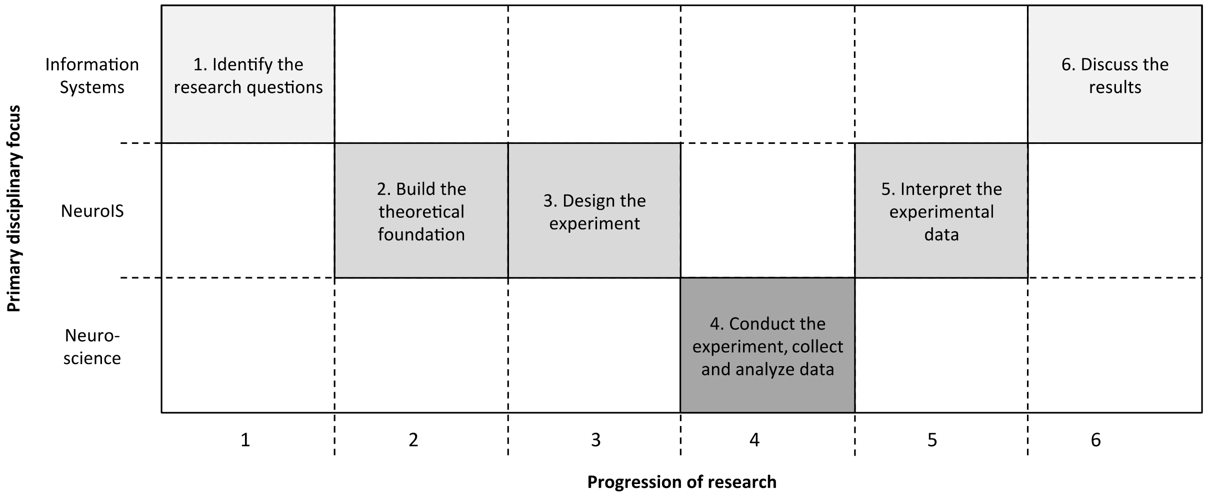

Figure 1: NeuroIS Research Framework

In the first phase, the research questions are identified based on prior literature in the field of IS, research objectives and justifications are identified, and specific research questions are formulated. The most important issue at this stage is the research's relevance and potential contribution to the IS field.

In the second phase, a solid theoretical foundation must be developed. This phase draws on the research questions identified in the first phase and builds on both IS and neuroscience theories to formulate hypotheses. Major challenges here are building a value proposition for IS theories by applying neuroscience knowledge and formulating hypotheses in such a way that they are meaningful for IS research and effectively measurable through neuroscience methods of inquiry. An iterative process is usually applied that requires knowledge from both disciplines.

Once the theoretical foundation is built, experiments can be designed in the third phase to collect evidence for hypothesis testing. Among other tasks, variables and measurement scales are defined, experimental treatments and procedures are planned, and participants are selected. Sometimes, existing paradigms in other neuroscience studies (such as the trust game) are adopted for NeuroIS research, but they must be carefully applied to reflect the context of information systems. The design of variables and measurements align with the research questions, hypothesis and experimental tasks requires expert knowledge in planning neuroscience experiments.

In the fourth phase, the experimental procedures are conducted according the experimental design, and experimental data is collected. Given the nature of neuroscience tools, this phase also includes data analysis, as researchers must have meaningful results ready for substantive analysis. This means, for instance, transferring the coordinates of measured brain activations into visual representations that color-code brain regions accordingly. The phase requires expert knowledge in the operation of neuroscience tools, such as knowledge about how to run an fMRI scan or about how to place EEG sensors on subjects. In general, this knowledge exceeds the boundaries of the field of IS because of biological and medical considerations. Depending on the tool, the neuroscience discipline has developed expertise on which NeuroIS can build.

In the fifth phase, the experimental data are interpreted referring back to the hypotheses. This phase relates to phase two, as it links the bio-data collected to findings for IS research. Again, knowledge from both disciplines is needed in order to make sense of the data collected from both a neuroscience and an IS perspective.

In the sixth phase, the results are discussed in terms of their impact on the IS discipline, including contextualizing the results in light of existing theory or developing new IS theories. This phase, essentially an IS research-related phase that links to phase one (since the neuroscience inquiry has been completed and has led to the results concluded in phase five), includes discussion of the extent to which the results complement existing IS research by, for example, explaining variances from existing theory. Both major contributions (e.g. considering subconscious effects) and major limitations (e.g. issues of instrument validity and external validity) that may result from the neuroscience strategy of inquiry need careful consideration in discussing the results. Table 1 summarizes and specifies the six phases according to their essential inputs and outputs.

Phase	**Input**	**Output**
1. Identify the research questions	- IS Literature	- Research objective(s) - Research justification(s) - Research question(s)
2. Build the theoretical foundation	- Research questions - IS theories - Neuroscience theories	- Theoretical research model - Hypotheses
3. Design the experiment	- Hypotheses - Existing IS or neuroscience experiments	- Experimental design (including e.g. tasks, treatments, measurements).
4. Conduct the experiment, collect and analyze data	- Experimental design - Neuroscience tools - Additional measurement tools	- Experimental data collection - Data analysis results (ready for substantive interpretation)
5. Interpret the experimental data	- Data analysis results - IS and Neuroscience theories	- Experimental findings - Interpretation of the findings
6. Discuss the results	- Interpretation of the findings - IS/Neuroscience Literature	- Theoretical contribution(s) - Practical implication(s) - Limitation(s) - Further research opportunities

Table 1: NeuroIS Phases

By positioning the phases both according to the progression of research and the primary disciplinary focus we intend to provide an orientation for researchers, reviewers, and readers, but we do not understand this assignment to be marked out selectively. The six phases of NeuroIS studies are not necessarily meant to be conducted in a linear manner. Such studies require anticipating later phases and reflecting prior phases, so an iterative flow to and from each phase must be considered. Still, the six phases mark essential steps in terms of the progression of completed research in NeuroIS. Likewise, the three layers distinguished regarding the disciplinary focus do not necessarily mean to differentiate three distinct disciplines. On the contrary, NeuroIS has been defined as a subfield of IS, and it can be characterized an applied field of neuroscience, in turn. The layers rather illustrates that activities differ regarding their focus either in IS, or in Neuroscience, or in the interface between the two requiring knowledge from both IS and Neuroscience.

Guidelines for High-Quality Neuroscience Research in Information Systems

Understanding NeuroIS studies as a strategy of inquiry in IS research, we can derive guidelines to assess the quality of the work (Table 2). These guidelines reflect the interdisciplinary nature of NeuroIS studies and relate essentially to quality criteria in both IS and neuroscience as well as criteria essential to interlinking the two fields.

The first guideline expresses that the points of departure and arrival of any NeuroIS study must be in the field of IS research, which means starting with a relevant IS research objective (phase 1) and concluding with findings that significantly advance the field (phase 6). Research opportunities through NeuroIS experiments might be taken into account when selecting and shaping research questions, but the resulting research must be motivated by and contribute to IS research. Further consideration of this guideline is needed when building the theoretical foundation (phase 2) as well as when interpreting the experimental data (phase 5).

The second guideline considers that the method of inquiry is that of a NeuroIS study; as such, the research must be valued based on the scholarly standards of neuroscience. NeuroIS studies must consider the large collection of theories and tools in the neuroscience literature , particularly when building theoretical foundations (phase 2), designing experiments (phase 3), conducting experiments, collecting and analyzing data (phase 4), and interpreting the experimental data (phase 5).

The third, fourth, and fifth guidelines focus on linking neuroscience and IS and relate to the challenges of applying tools and theories to the study of IS research topics. These three guidelines affect how the theoretical foundation is built (phase 2), the experiment is designed (phase 3), and the data is interpreted (phase 5). Together, these guidelines consider specific challenges of applying neuroscience in IS research, as opposed to other fields of applied neuroscience. Table 2 summarizes the guidelines with reference to the phases of a NeuroIS study in which they predominantly need to be considered.

Guideline	Description	Predominant Phases					
		1	2	3	4	5	6
1. Advance IS research	A NeuroIS study needs to compellingly show relevance for the IS field, as to both research objectives and findings (Relevance for IS).	X	X			X	X
2. Apply the standards of neuroscience	A NeuroIS study needs to demonstrate meeting state-of-the-art knowledge in all related considerations to neuroscience (Rigor		X	X	X	X	

	as to Neuroscience).						
3. Justify the choice of a neuroscience strategy of inquiry	A NeuroIS study needs to convincingly argue on the appropriateness of the research method applied in meeting the research objectives, and findings need to be discussed in light of this decision (Appropriateness of Method).		X	X		X	
4. Map IS concepts to bio-data	A NeuroIS study needs to clearly state what IS concepts are measured by which bio-signals, and it needs to be argued why this is an appropriate measure, as well as data needs to be carefully interpreted in light of this mapping (Instrument Validity).		X	X		X	
5. Relate the experimental setting to IS-authentic situations	A NeuroIS study needs to argue what measures were taken in the research design to foster external validity, and data needs to be carefully interpreted in light of these measures (External Validity).		X	X	X	X	

Table 2: NeuroIS Guidelines

Our purpose in establishing these guidelines is to assist researchers, reviewers, editors, and readers in understanding the requirements of effective neuroscience research in IS. Like Klein and Myers [19] and Hevner et al. [16], we advise against mechanical use of the guidelines in favor of using expertise and judgment to apply the guidelines in light of a specific research project’s requirements. The guidelines indicate critical considerations in a NeuroIS experiment, but the quality of any one study is determined by how well the intent of the guidelines is met. What’s more, the guidelines are not considered complete but are a starting point from which to collect additional knowledge on the challenges that arise when planning and evaluating NeuroIS studies in IS. Therefore, we invite fellow researchers to extend the set of guidelines.

In the next section, each guideline is discussed in detail and illustrated with selected examples.

Guideline 1: Advance IS Research

As a sub-area of IS, NeuroIS studies must contribute to knowledge on the design, use, or impact of information systems. March and Niederman [26] discuss the danger of IS research that originates from methodological, rather than IS research problems. NeuroIS does not relate to a special field of application but applies “neuroscience theories, methods, and tools” [10]. Therefore, the first guideline is that NeuroIS studies must advance IS research. Studies that originate from applying neuroscience strategies of inquiry, rather than from contributing to IS theory, are not beneficial to the field.

Advancing the field of IS research includes contributions to behavioral and design-oriented research, both of which are addressed by NeuroIS [33]. While NeuroIS studies in behavioral research are conducted to describe, explain, and/or predict people’s IT-related behavior, NeuroIS studies in design science research are conducted to further the design and evaluation of IT artifacts[46]. Prior research has identified the potential contributions of NeuroIS studies as facilitating/enhancing existing IS theories, developing new theories, facilitating system design, evaluating system design, and improving how existing constructs are measured [22]. Three strategies have been derived for design-oriented research: the use of neuroscience theories to inform the building and evaluation of IT artifacts, the use of neuroscience tools to evaluate IT artifacts, and the use of neuroscience tools as built-in functions of IT artifacts [45]. These strategies can help to indicate how contributions from NeuroIS studies impact information systems design.

As a guideline for NeuroIS studies, advancing IS research particularly manifests in two phases of the process model for NeuroIS studies in Table 1: First, NeuroIS studies must be grounded in research problems that are well-positioned in the field of IS research (phase 1). In particular, research questions must be formulated in, clearly contextualized in, and relevant to IS research. Second, the findings of a NeuroIS study must be clearly stated and put into context with the extant state of the art in the field. Therefore, relating the findings of a study with existing IS theory is another important step in discussing results (phase 6). In order to make sure that the NeuroIS investigation is contextualized well in the IS literature, further consideration of this guideline needs to be taken when building the theoretical foundation (phase 2) and when interpreting the experimental data (phase 5).

As examples, the studies presented in this special issue contribute to a variety of important IS research areas, including e-commerce [20], virtual collaboration [27], software gaming [21], technology acceptance [31], emotions [15], and trust [36]. The studies are mainly behavioral in that they contribute to theory that explains the behavior of people who use IT. At the same time, all six studies illustrate how their findings can inform the design of IT artifacts. We use Kuan et al. [20] and Ortiz de Guinea et al. [31] to illustrate this guideline further.

The popularity of social media like Facebook and Twitter has motivated rapidly increasing interest in social commerce research. Kuan et al. [20] investigate the influence of “buy” and “like” information on buying decisions on group buying sites (e.g., Groupon). The study suggests that social influence, such as that arguably exerted by “buy” information, is driven by the need to be right. However, normative social influence, such as that arguably exerted by “like” information, is driven by the need to be liked. The study also finds that the social influence exerted by “buy” information is primarily informational, whereas the social influence exerted by “like” information is primarily normative. These findings inform the design of group buying platforms as to which mechanisms influence purchasing behavior.

IS adoption, perceived usefulness (PU), and perceived ease of use (PEU) are important IS concepts that have been investigated extensively. Ortiz de Guinea et al. [31] adds value to this stream of research by revealing the importance of the neurophysiological states of “engagement,” “frustration,” “memory load,” and “distraction” in predicting technology acceptance. The authors find that, distraction does not affect PU when engagement is high but that it has a negative and significant effect on PU when engagement is low. In addition, they find that memory load has a negative effect on PEU when frustration is high but a positive effect on PEU when frustration is low. Among others, these findings make new contributions by suggesting that technology need not be simple to be perceived as easy to use, so IS design should aim instead at maintaining low frustration and high engagement levels to foster technology acceptance.

Experts from the IS research areas to which a NeuroIS study intends to contribute should be involved in the review process in order to ensure that the paper is convincing for IS experts with no particular background or interest in NeuroIS. Therefore, NeuroIS papers should be structured to contain special sections for the IS audience, specifically regarding phase one and phase six. Such an arrangement not only supports the review process but also helps to ensure that the findings of NeuroIS papers are disseminated to a wide IS audience.

Guideline 2: Apply the Standards of Neuroscience

The IS discipline uses research methods from both natural science and design science. There is experience in, for example, survey development and structural equation modeling for quantitative studies, as well as in case-study research and the grounded-theory method for qualitative observations. Methods like software engineering, conceptual modeling, and design thinking applied to guide the design of IS are part of educational programs at universities and are well understood by scholars in the NeuroIS community.

NeuroIS studies must meet the scholarly standards defined in the field of neuroscience. The competencies required extend to the cognitive psychology and medical fields, which are relatively new to IS and are a different type than those of the social and technical sciences. It is therefore important to follow the general guidelines for designing experimental tasks for the chosen neuroscience tools. Standards are continuously developed by, among others, medical doctors and neuroscientists who specialize in brain functional, genetics, or neuro-physiological observations. In NeuroIS, no valid conclusion can be drawn from data if scholarly standards from the field of neuroscience are not rigorously met, as there is a danger of jumping to conclusions too soon that do not hold either because of flaws in operating tools, preparing stimuli, or sampling or because important related work has been overlooked. It would not be beneficial for the field of NeuroIS, if studies published in IS journals used neuroscience strategies of inquiry that were substandard (or wrong) compared to the state of the art in neuroscience.

Applying standards of neuroscience manifests in four phases of the NeuroIS process model: phase 2 (build a theoretical foundation), phase 3 (design the experiment), phase 4 (conduct the experiment, collect and analyze data), and phase 5 (interpret the experimental data). IS scholars are advised to team with experts in neuroscience (e.g., [37]) in order to gain advantages in terms of quality of research and economies of scale.

As examples, the studies in this special issue use several NeuroIS methods as strategies of inquiry, including brain-imaging tools like fMRI in [36] and EEG (electroencephalography) in [15, 20, 21, 27, 31], as well as neurophysiological measures like EDA (electrodermal activity) and EMG (facial electromyography) in [27]. Each study details the methodological considerations it undertook in applying its measurement methods.

These studies show that the standards that apply depend on the neuroscience method chosen and include knowledge and experience in handling the measurement devices. At the same time, substantive knowledge on the related neurophysiological anatomy is needed in order to make the right measurement decisions and to understand the data collected. For example, Li et al. [21] report on an experiment in their EEG study that involves "44 participants (21 males and 23 females […] without medical implants, mental disorders, and physiological problems and [who] were treated based on screening guidelines. In this study, "[a]n Emotiv EPOC 14-channel (AF3/4, F7/8, F3/4, FC5/6, T7/8, P7/8, and O1/2) wireless EEG system […] was used to track and record the EEG data at 128 Hz" [21]. Riedl et al. [36] explain in their fMRI study that they "acquired 2 runs of 690 functional T2*-weighted echoplanar images (EPI) [TR, 2 s; echo time (TE), 40 ms; flip angle, 90°; field of view, 256 mm; matrix, 64 x 64 mm; 26 axial slices approximately parallel to the bicommissural plane; slice thickness, 4 mm]" [36]. Further they report that "for registration purposes, a high-resolution T1-weighted structural image (MPRAGE) was acquired from each participant [TR, 20 ms; TE, 5 ms; flip angle, 30°; 179 sagittal slices; voxel size, 1 × 1 × 1 mm]" [36].

On a more general level, the studies confirm our previous discussion that the accomplishment of a rigorous NeuroIS study exceeds the core knowledge of the IS field, as it extends to the psychological and medical fields. Therefore, in order to evaluate how well a NeuroIS study conforms to the standards of neuroscience, it would be appropriate to have experts from the related fields of neuroscience involved in the review process, at least in this early stage of area development.

Guideline 3: Justify the Choice of a Neuroscience Strategy of Inquiry

The IS field is characterized by a high level of diversity in the problems it addresses, the theoretical foundations it uses, and the methods of data collection and analysis it applies [3, 38]. Since it lacks a dominant research paradigm, the IS discipline has been described as pre-paradigmatic or multi-paradigmatic [43]. The epistemological perspectives that IS researchers can use also differ widely [29]. With behavioral research and design research, these two major paradigms draw from diverse qualitative and quantitative approaches to collecting data or from a combination of both in mixed-methods research, including surveys, case studies, and experiments.

Given the methodological diversity of the field, it is particularly important that NeuroIS justify its advantages compared to those of other strategies of inquiry [10] because of the economic effects related to this particular strategy of inquiry. Vom Brocke et al. [45] discuss a number of strategies that use neuroscience in design-science research and differentiate factors like applicability, cost, accessibility, required knowledge, and available references. While NeuroIS requires generally high levels of investment compared to those required by other inquiry strategies, such as surveys and interviews, the economic effects vary according to the specific tools applied. While brain-imaging tools like EEG and fMRI are relatively costly, neuro-physiological tools like skin conductance are not. Each tool offers its own measurement opportunities as well. ([10] and [33] provide overviews of tools.) In addition to the requirement for a neuroscience method of inquiry in a NeuroIS study, the specific tool selection must be convincing.

Justifying the choice of a neuroscience strategy of inquiry manifests in phases 2 and 3. In order to developing the research design (phase 3), the researcher must provide a well-grounded argument from neuroscience literature or theories regarding the extent to which we can expect the data to be compelling (phase 2). Prior research has reported major strengths of neurophysiological measurement because neurophysiological tools are particularly valuable for measuring IS constructs that people are either unable, uncomfortable, or unwilling to truthfully self-report. This may include sensitive issues (e.g., gender, race, culture, religion), personal issues (e.g., goals or fears), deep or hidden emotions (e.g., guilt, fears, and anger), automated processes (e.g., habit and automaticity), complex cognitive processes (e.g., cognitive overload), social dynamics (social cognition), antecedents of human behaviors (e.g., beliefs, attitudes, and intentions), and moral issues (e.g., ethics and moral judgments). [10]

Therefore, the argumentation is most compelling when, building on these strengths, the observation that is of value to information systems is possible particularly (or even only) through the lens of a neuroscience strategy of inquiry. In addition to a neuroscience strategy in general, the choice of a specific neuroscience tool for data measurement is required. It is important to consider the strengths and limitations of different tools. For instance, EEG has high temporal resolution but low spatial resolution, while fMRI is the reverse ([33] provide an overview of tools and their characteristics). Also, data interpretation (phase 5) should link to the expectations and discuss the extent to which the results were possible because of the lens of neuroscience.

For instance, Kuan et al.'s [20] investigate levels of emotional response to different types of group-buying Information, among others, which would have been possible without using neuroscience methods. Similarly, Riedl et al. [36] ask whether differences in trustworthiness-discrimination abilities based on whether the interaction partner is a human or an avatar are associated with neural differences. Other studies focus on concepts on which neuroscience evidence will be able to provide unique insights, such as engagement [21] and positive and negative emotions [15].

Apart from the general choice of a neuroscience strategy, the studies also address the choice of specific neuroscience methods. Primarily, this choice relates to the data that can be measured using a specific method. Minas et al. [27], for instance, combine methods in order to collect different types of bio-data. As the authors report: "First, we use electroencephalography (EEG) to measure the cognitive response to informational statements that present new facts about the decision alternatives. Second, we use changes in electrodermal activity (EDA), and facial electromyography (EMG) to measure the emotional response to this information." [27]

In some cases alternative methods were available, so such methods are compared. For example, in their EEG study, Kuan et al. [20] argue that "[c]ompared to the MRI and PET, the EEG is relatively unobtrusive and portable" [20]. Further they explain that "[EEG] is equipped with better temporal resolution (in the order of one millisecond), making it particularly useful for studying cognitive and emotional responses in natural settings" [20]. Likewise, Ortiz de Guinea et al. [31] argue that “EEG complements fMRI approaches used in previous IS research by allowing for the recording of brain electrical activity while the user interacts with a technology” [31]. In this regard, the authors have applied selection criteria for NeuroIS tools mentioned above, such as applicability and accessibility.

Finally, the specific requirements of a research design also lead to favoring certain methods. Ortiz de Guinea et al. [31] argue that “due to good temporal resolution, changes in the oscillation of EEG signals can ´accurately reflect subtle shifts in alertness, attention, and workload that can be identified and quantified on a second-by-second time-frame´ [...]“ [31].

In sum, all of the studies in this issue are examples of applying the neuroscience strategy of inquiry in order to achieve relevant findings that were possible only thorough this inquiry strategy. In order to evaluate the appropriateness of the methodological choice, knowledge about a wide spectrum of methods, along with the strengths and weaknesses of extant studies, is valuable. Therefore, we recommend involving experts who are experienced in applied areas of neuroscience as both co-researchers and reviewers. Given that NeuroIS is still an emerging field, experts from other fields of applied neuroscience, such as neuro-economics and neuro-marketing may also be involved.

Guideline 4: Map IS Concepts to Bio-Data

Although the intellectual core of IS research has produced only a few of its own theories, the many theories and constructs borrowed from its reference disciplines form the foundation of the discipline. The concepts in IS research continue to evolve, and often the discipline has to deal with buzzwords that emerge in the IT software and consulting markets only to disappear quickly. This situation poses special challenges for measuring IS concepts, particularly using neuroscience tools.

It is essential that NeuroIS studies measure IS-related concepts correctly in order to ensure construct validity. The bio-data collected does not usually directly measure variables that are meaningful for IS research, so IS concepts are not directly measurable through bio-data. For example, brain-image data may be organized by (x, y, z) values of MNI coordinates (MNI = Montreal Neurological Institute) to indicate that certain brain regions are activated, or data may show a certain EDA value, a neurophysiological measure that reliably captures autonomic nervous system activity. We need to know what these data tells us about the design, use, and impact of information systems.

Most IS concepts are not directly measurable through bio-data. A survey may measure the variable “ease of use” using a Likert scale from 1 to 5, but the question remains concerning how one can measure ease of use using a neuroscience method of inquiry. Usually, there is no direct measurement, so it is necessary to build on prior knowledge, that is, neuroscience theory or other literature to determine which bio signals (e.g., activations of brain regions) may be used to measure certain variables. For example, the variable “perceived usefulness” may be measured through activation of the caudate nucleus and the anterior cingulate cortex in response to anticipated rewards [11]. Even so, variables like satisfaction and enjoyment are not equivalent to ease of use.

In some cases IS constructs may be measured through neuroscience constructs directly, as when both fields share the same (or related) constructs, as is the case with the construct of “stress.” Stress caused by technology, called technostress [5], has a long tradition in IS research; stress has been extensively researched in neuroscience; and stress hormones, such as cortisol and adrenaline, are well-understood bio-signals used to measure stress [44]. In a study that investigates techno-stress by means of cortisol measurement, Riedl et al. [35] show that an error message is an acute stressor that may elicit cortisol elevations as high as stress situations like public speaking and derive a number of insights on the design and use of information systems from these findings.

In general, neuroscience theory is used to map bio-signals to concepts that characterize the effects that experimental stimuli have on subjects. Dimoka, Pavlou and Davis [12] summarize the neural correlates of a number of IS concepts and distinguish decision-making processes, cognitive processes, emotional processes, and social processes. Mapped concepts of decision-making include uncertainty, risk, ambiguity, rewards, and utility, while cognitive processes involve such brain areas as those for information processing, cognitive effort, multi-tasking, habit, and flow. Concepts for emotional processes include pleasure, displeasure, happiness and sadness, fear, and anger, while social processes include concepts like social cognition, trust and distrust, and cooperation and competition.

A mapping of IS concepts that allows for experimental measurement may not be available for a number of research problems relevant to IS, so studies should be conducted to develop neuroscience measurement instruments for IS-specific constructs. We refer to these studies as *exploratory NeuroIS studies*, as they explore neural and neuro-physiological correlations for IS-specific constructs. Dimoka and Davis' seminal article [11], "Where Does TAM Reside in the Brain?" is an example of such an exploratory study.

Another strategy for developing experimental measures is to use concepts from reference disciplines that have been measured in neuroscience or other fields of applied neuroscience. For example, trust has been investigated in neuromarketing, and stress has been the subject of research in neuropsychology. Other concepts, such as cognitive load and cognitive conflict, have been the subjects of neuroscience research in general and may be used to study IS-related concepts as well. Studies can also be conducted to verify measurement instruments for IS research that have been used in other fields. In such *confirmatory NeuroIS studies*, research is designed based on existing knowledge in order to verify related knowledge in IS research.

Mapping concepts to bio-signals in NeuroIS studies requires careful consideration of the state of the art of both IS and neuroscience. Drawing from marketing research, Huettel and Payne [17] observe that there is seldom a one-to-one correspondence between a neurophysiological measure and a theoretical construct, so Dimoka et al. [10] suggest treating neurophysiological measures in IS "as proxies for complex theoretical concepts (similar to all measures)" [10].

Neuroscience is a rapidly developing field characterized by diverse positions regarding measurement. For example, the neural implementation of "creativity", a concept of increasing importance in IS research [6, 39], has been extensively investigated in neuroscience and in the subfield of "cognitive neuroscience of creativity" [8] in particular, but there is still no established method of measurement with which to identify creative thinking through activated brain regions. Research has reported on the role of the prefrontal cortex in creativity, but it has also shown that many regions are activated. Ultimately, activation patterns that would facilitate the measurement of the degree to which a stimulus (e.g., a specific representation of a process model) facilitates creative thinking in comparison to another stimulus (e.g., a competing model representation) is not yet available. Figure 2 sums up the discussion by showing a conceptual linkage between bio-data and IS concepts.

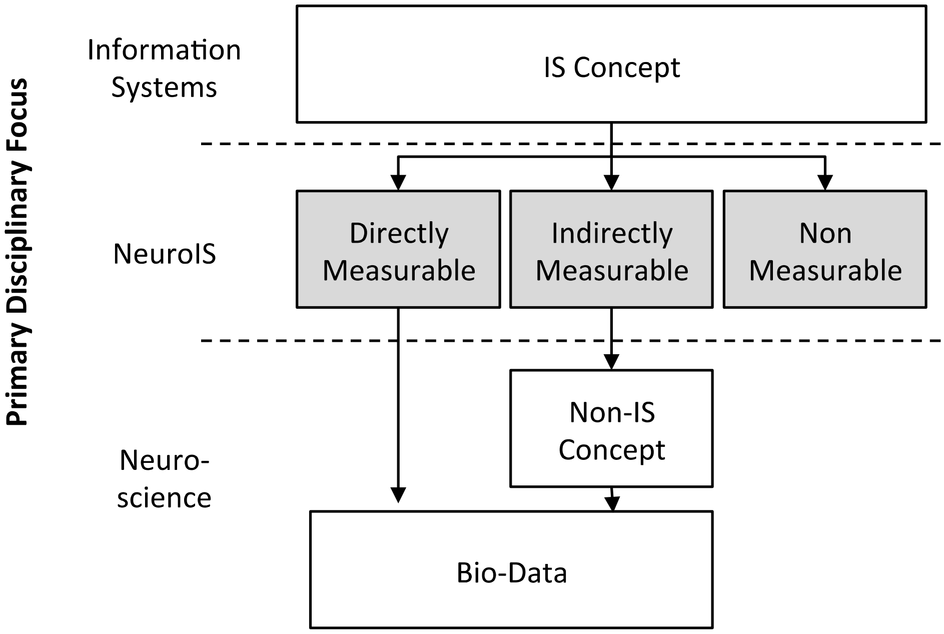

Figure 2: Mapping IS Concepts and Bio-Data

Decisions about mapping IS concepts to the bio-data should be rooted in theory (phase 2), be manifested in the experimental design (phase 3), and considered in interpreting the experimental data (phase 5). When considering the application of neuroscience studies as a strategy of inquiry for individual research interests, researchers are advised to evaluate the measurability of the constructs of interest first. Since rigorous measurement is a prerequisite for every NeuroIS study, the availability of according theory can also influence the choice of research questions (phase 1) and hypotheses (Phase 2). An iterative process of shaping the study in terms of how concepts that are both relevant to IS and rigorously measurable through bio-data is often required.

For example, Minas et al. [27] and Guinea et al. [31] measure the concept of “memory load,” which is a well-understood concept in neuroscience, associated with the Dorsolateral Prefrontal Cortex. By building the study on established constructs from neuroscience, such as “memory load,” the researcher can base the measurement of this construct on extant research. Ortiz de Guinea et al. [31] measure memory load as “the brain electrical activity occurring in the frontal midline (Fz) for the theta frequency (4-7Hz),” [31] as suggested by and applied in many prior studies.

In some cases, however, further argumentation is needed in order to identify the right bio-data for measuring the concept of interest. For example, Ortiz de Guinea et al. [31] measure the concepts of *distraction* (D) through EEG, arguing that “D was measured via an index that calculates the probability of the individual being distracted, based on previous literature on attention, vigilance, and alertness [...]” [31]. Further they explain that “[t]his literature has calculated distraction related measures by combining frequency bins in the theta, alpha and beta bands” [31]. Based on the literature, the authors build their measurement on a four-class “alertness” index that was previously suggested and “is calculated using absolute and relative power spectra from channels FzPOz and CzPOz of the theta, alpha, and beta frequencies [...]” [31]. The authors conclude that they “took the ‘distracted’ component of the four-level ‘alertness’ index in order to measure D” [31].

These examples illustrate our observation that, in principle, collected bio-data does not directly measure variables that are meaningful for IS research and how careful authors can argue based on the extensive neuroscience literature. As to the evaluation of the mapping quality, the same considerations apply as to guideline 3.

Guideline 5: Relate the Experimental Setting to IS-Authentic Situations

IS research investigates socio-technical systems [25], a research field that is neither pure social science nor pure natural science and that bridges technical design and social behavior [14]. Topics of interest to IS researchers include IT and organizations, IS development, IT and individuals, IT and markets, and IT and groups [40]. The unit of analysis, which can be the individual, group, organization, or market [40], also varies widely in IS studies [13]. Research should account for the dynamics that emerge during interactions between people and technologies in design and implementation processes (e.g., [28]) and in adoption and use processes (e.g., [7]).

Specific experimental settings apply in NeuroIS studies that must be related to IS-authentic situations in order to establish external validity. For example, subjects in fMRI studies lie in a scanner as they are exposed to the experimental stimulus or task, but people do not lie in scanners in authentic IS situations. In addition, the behavior under observation may be influenced by factors that are not present in the experimental setting, especially those that evolve through the interaction of individuals and technology in complex contextual settings. Therefore, relating the experiment to an IS-authentic context is an issue of external validity in NeuroIS studies.

Relating the experiment to an IS-authentic context requires adherence to at least three challenges: First, observations are limited to the bio-data taken from a certain sample, and in NeuroIS studies, such sample sizes are comparably small. Even neuroscience studies in prestigious journals like *Neuron*, *Science*, and *Nature* have average sample sizes of only eighteen [24]. Even though small sample sizes meet scholarly standards, from an IS behavioral perspective, the generalizability of the findings of such studies may be limited. Research must control for individual effects of single subjects in the sample population, and the discussion of results should account for this limitation.

Second, observations are limited to the experimental environment in which they were made, and neuroscience measurement may set even stronger standards for authenticity than is the case for experiments in general. Here, the tool selection (phase 3 and guideline 3) plays an important role. For instance, neurophysiological tools allow measurements to be made in a wide range of contexts and interactions in socio-technical systems, such as role-plays [46].

Third, observations take place on the individual level, so conclusions on the group, organizational, or market level must be made carefully. Individual behavior may underlie the phenomena studied on the group or organizational level, but other factors, such as group dynamics and organizational context, may also influence these phenomena.

Relating the experimental setting to IS-authentic situations manifests in phase 3 (design the experiment), phase 4 (conduct the experiment, collect and analyze data), and phase 5 (interpret the experimental data). Also, authenticity is influenced by considerations taken when building the theoretical foundations of the experiment (phase 2). As a general strategy, triangulation across several measures has been suggested both in general research [42] and in NeuroIS research in particular [10]. A number of NeuroIS studies, such as Riedl et al. [34] and vom Brocke et al. [46], have used additional data sources, including log files, performance data, and psychometric data. Then NeuroIS measurement is applied to the investigation of differences in behavioral data, and behavioral studies are used to isolate particular research questions to be investigated using NeuroIS inquiry strategies, which are subsequently interpreted (phase 5) in the context of additional data.

In addition, data interpretation must discuss the extent to which the results from the experiment can be transferred to IS-authentic contexts, which limitations must be considered, and which conclusions might be drawn in light of further observations.

The studies included in this issue provide many examples of how to foster external validity. Basic considerations relate, for example, to preparation of the stimulus material and selection of the participants. For example, Li et al. [21] choose real-life gaming software, and Kuan et al. [20] select participants who are also connected as friends on Facebook. More specifically, examples show how triangulation can be applied to foster external validity. For instance, Li et al. [21] report that “EEG is adopted and supplemented by other traditional post-game data collection methods” [21]. They further argue that “[t]he multi-method approach allows us to triangulate and better understand the relationship between gaming elements and user–game engagement” [21]. The studies confirm the strategy of first determining a specific behavior through strategies of inquiry, such as surveys or conventional experiments, and then explaining the behavior through neuroscience methods of inquiry. Riedl et al. [36] first conduct a pre-test with 45 subjects to rate the trustworthiness of 80 actors (40 human and 40 avatar faces) on a 7-point Likert scale. Using to a rigorous process, the authors identify 16 faces that differed significantly in terms of their perceived trustworthiness, and these faces were used in the fMRI experiment in which the participants played the trust game against both humans and avatars. The studies also show that devices differ based on the laboratory requirements, as in Li et al. [21] and Kuan et al. [20], who use wireless EEG headsets. We can expect that the technological process will help to ensure that neuroscience measurement is applied in more authentic IT-use situations.

These examples show that, even when the collection of bio-data takes place in a laboratory setting, the overall research design can be set up in a way that increases external validity. The evaluation of the appropriateness of the decisions in both planning and reviewing related research should lie in the hands of scholars who have experience with applied neuroscience studies.

Summary of the Guidelines

Based on the discussion above we can summarize a number of evaluation criteria for NeuroIS studies as described in table 3.

Guideline	Exemplary Evaluation Criteria
1. Advance IS research	- Is the study sufficiently positioned in prior research in the field? - How significant is the increase in knowledge on development, use or impact of information technologies, e.g. through better measurement, theory or design? - To what extent does the work open up to future research opportunities?
2. Apply the standards of neuroscience	- Is the experimental design adequately based on solid research in related fields of neuroscience? - In how far have guidelines been considered for the application of the chosen neuroscience tools? - How comprehensible is the interpretation of the results supported by neuroscience theory?
3. Justify the choice of a neuroscience strategy of inquiry	- How convincing are the advantages of using a neuroscience strategy of inquiry presented (compared to other strategies of inquiry)? - To what extent is the choice of the specific neuroscience tool (compared to other neuroscience tools) substantiated? - How accurate are potential limitations of specific tools at hand considered and mitigated by complementary data collection methods?
4. Map IS concepts to bio-data	- In how far does bio-data measure the IS concept of interest and how solid is this measurement covered by neuroscience theory and existing studies? - To what extent are the IS concepts, which are measured, appropriate when considering both the IS research questions and the measurement opportunities of neuroscience tools?

	- How appropriate is the interpretation of the experimental data particularly when taking potential limitations resulting from the mapping into account?
5. Relate the experimental setting to IS-authentic situations	- To what extent does the experimental design reflect realistic use situations of the information systems under investigation? - In how far have the findings been validated by triangulating data from different methods? - How appropriate is the interpretation of the experimental data, specifically when considering potential limitations resulting from the experimental setting?

Table 3. Sample Criteria for Evaluation

Discussion and Implications

Given the focus of IS research on IT that is actually in use, understanding the neuro-biological factors that are related to this use is of central interest to the field of NeuroIS. Research can reveal emotional and affective effects that are related to the design and use of information systems, which adds to IS research because such subconscious effects, which occur before external behavior is manifested, could not be observed previously. Research has shown that emotions play an important role in a number areas, including technology acceptance [12], IS use [41], and IS success [32]. The rise of Apple products, for instance, has often been related to emotional effects, rather than only to functionality [1]. Ortiz de Guinea and Markus [30] suggest that new theoretical lenses are needed to clarify IS behaviors because theories based on concepts that frame human decision-making as an entirely rational activity fail to account for the automatic and subconscious information-processing that underlies human judgment and decision-making [30]. Therefore, additional theory on the human factors that underlie the use of IT could advance the field significantly.

Two threats must be managed in order to leverage NeuroIS's potential. First, we should not apply neuroscience as a means in itself but only to advance the IS discipline. We argue from an IS scholar's perspective that IS comes first and that neuroscience serves a valuable means by which to study IS phenomena. Second, we should conduct research that meets the standards of the field of neuroscience. While the application of neuroscience is new to IS, decades of research have investigated neuroscience as a discipline [24]. There is no reason to compromise the quality of NeuroIS research. So the NeuroIS guidelines emphasize that NeuroIS must make a strong contribution to the field of IS (guideline 1), that the method must be chosen accordingly (guideline 3), and that neuroscience standards must be met in the experiment (guideline 2).

We suggest specialization as a strategy with which to leverage NeuroIS. The NeuroIS guidelines indicate three fields of specialization: IS, neuroscience, and NeuroIS. While earlier contributions considered the first two fields in particular, linking the two fields calls for a special set of competencies that neither IS nor neuroscience scholars usually command: particular knowledge of and experience in crafting hypotheses, building on both IS and neuroscience theory (phase2); designing the experiment (phase 3); and interpreting the experimental data (phase 5). Challenges specific to NeuroIS relate to justifying the choice of a neuroscience strategy of inquiry (guideline 3), mapping IS concepts to bio-data (guideline 4), and relating the experimental setting to IS-authentic situations (guideline 5). Knowledge from both neuroscience and information systems is needed to master these challenges, and this knowledge includes NeuroIS as a distinct field in academia and practice.

In general, the NeuroIS guidelines help researchers by serving as an orientation for scoping NeuroIS research from an IS perspective. The guidelines and phases could also contribute to a methodology of NeuroIS studies that will help all stakeholders in planning their work and/or evaluating and understanding the contribution of the work of others. Arranging a paper according to the six phases and explicitly stating how the five guidelines have been addressed can help stakeholders to read, review, and refine papers from specific perspectives. In particular, special sections in research papers that clearly outline neuroscience-, NeuroIS- and IS-related considerations will help to improve the effectiveness of NeuroIS research.

The high degree of specialization we call for may also lead to innovative ways of organizing the research community. Sharing knowledge and expertise through such means as networks, virtual research clusters, and shared facilities (e.g., laboratories) is beneficial to the field. Exploring the degree to which authorship can be determined based on contributions to research means that one team of scholars could position and discuss the study in IS (phases 1 and 6), while another team builds the theoretical foundation, develops the experimental design and interprets the experimental data (phases 2, 3 and 5), and a third team conducts the experimental procedures (phase 4). Thus, the field of NeuroIS could set an example for many other areas of research in terms of how to organize multi-disciplinary research. For example, Liang et al.'s [23] study was conducted by a team of neuroscientists and IS scholars to investigate how online personalization impacts perceived closeness and purchase intention.

Specialization could also be of immediate value to the field. There is no need for IS researchers in general to study the various neuro-biological mechanisms in depth or to learn how to conduct measurements like fMRI brain scans to benefit from NeuroIS research. IS scholars are encouraged to read and research selectively since they are primarily interested in contributing to IS. The same holds true for editors and reviewers, who are encouraged to involve experts from relevant reference disciplines. We trust that such a practice will improve the quality of work and facilitate the new NeuroIS studies that bear high potential.

NeuroIS will play an increasingly important role in IS research, and the technological advancements in the field of neuroscience will contribute to this development. Measurement devices that lower the cost of investing in and appropriating these tools are already available [37]. In the future, standards will evolve and lead to more pragmatic applications of neuroscience measurement, including devices like bracelets and caps for data collection in the field, software tools for data analysis, and reference models and patterns for research design. Research in the areas of big data analytics, including neuro-biological data, is already a promising source for facilitating neuro-adaptive IT artifacts [45].

NeuroIS must consider the specific characteristics of IS research, and NeuroIS may not be applied to all IS research questions, as its applicability is limited to areas in which e.g. both the mapping of IS concepts to bio-data (guideline 4) and the relationship to an IS-authentic context (guideline 5) can be sufficiently ensured. Such prerequisites might not be fulfilled in a number of areas, and NeuroIS is not a valid strategy of inquiry in these cases (guideline 3). As Dimoka et al. [10] indicate, “NeuroIS is not a panacea for all IS research issues,” and its limitations increase as the phenomenon of interest becomes more complex. However, NeuroIS goes hand-in-hand with both IS and neuroscience, and since both fields are developing fast, areas that might not be observable today may well be observable tomorrow.

The effective presentation of NeuroIS research in major IS journals like *ISR, JAIS, JMIS*, and *MISQ* will be an important step toward capitalizing on the potential of neuroscience in IS research.

Conclusion and Outlook

This study presents guidelines for neuroscience studies in IS research that require that such studies advance IS research, apply the standards of neuroscience, justify the choice of a neuroscience strategy of inquiry, map IS concepts to bio-data, and relate the experimental setting to IS-authentic situations. These guidelines highlight critical factors and present normative advice for conducting NeuroIS studies. The guidelines are related to the six phases of a NeuroIS study: identify the research questions; build the theoretical foundation; design the experiment; conduct the experiment, collect and analyze data; interpret the experimental data; and discuss the results. We emphasize the IS perspective in NeuroIS, recognizing neuroscience studies as inquiry strategies in IS research. As such, three areas of expertise are distinguished—IS, NeuroIS, and neuroscience—with each study starting and ending in IS and using means from neuroscience through NeuroIS as a linking discipline. We exemplify our understanding on the basis of six NeuroIS studies, highlight the potential and challenges of NeuroIS studies, and discuss specialization in all levels (IS, NeuroIS, and neuroscience), as well as collaboration among these levels. These insights allow a larger community of IS scholars to engage in NeuroIS studies and build on their results.

This paper has a primary limitation that suggests areas for future study. The guidelines we present are influenced by our personal views, by our research experience, and by the comments from many expert reviewers in IS and neuroscience we read while handling this special issue. Other researchers may come to other conclusions, so we do not consider the guidelines a complete set so much as a starting point from which to invite fellow researchers to add their views. Knowledge on NeuroIS studies should be furthered from a variety of perspectives in order to complement a NeuroIS research methodology because the potential of neuroscience for IS research is significant. However, there are also threats if studies fail to show relevance and rigor. We hope the guidelines we present can help in this regard and that they will be considered useful by researchers, editors, reviewers, and readers.

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