Information Systems 89 (2020) 101462

Contents lists available at ScienceDirect

Information Systems

journal homepage: www.elsevier.com/locate/is

# What does existing NeuroIS research focus on?

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ARTICLE INFO

*Article history:*
Received 24 August 2019
Received in revised form 24 October 2019
Accepted 25 October 2019
Available online 28 October 2019
Recommended by D. Shasha

*Keywords:*
NeuroIS
Literature review
Stimulus–organism–response theory
Neuroscience tools
Information systems

ABSTRACT

NeuroIS is a research field in which neuroscience theories and tools are used to better understand information systems phenomena. At present, NeuroIS is still an emerging field in information systems, and the number of available studies is limited. Because researchers who plan or execute NeuroIS research need to understand the status of the existing empirical research published in relevant journals, we have analyzed 78 empirical articles and put forward an integrative framework for understanding what existing NeuroIS research focuses on. Our framework is built upon stimulus–organism–response theory, which explains that stimulus factors can affect users' psychological processes, which further lead to their responses. Then, we review the collected articles and summarize their findings to give more details of NeuroIS studies. Through this literature review, we identify several opportunities for future NeuroIS research in terms of influencing factors, measurement instruments, and subjects. We believe that our work will provide some meaningful insight for future NeuroIS research.


**Contents**



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https://doi.org/10.1016/j.is.2019.101462
0306-4379/

## 1. Introduction

To understand the complex phenomena in information systems (IS), scholars has long referenced the knowledge of other disciplines. By directly or objectively measuring human brain activities, cognitive neuroscience has made a great deal of progress in understanding human behavior, informing IS research [1]. From this cross-fertilization of disciplines, the field of Neuro-Information Systems (NeuroIS) emerged. Since the concept of NeuroIS was put forward, a number of IS researchers have started to use neuroscience theories and tools to better understand human psychological processes in IS contexts [2]. The NeuroIS literature offers new insights for IS-related issues by examining neurophysiological effects associated with the design, use, and impact of IS. By using neuroscience theories, tools, and methods, NeuroIS research is expected to be less biased, and it can examine human behavior at the underlying neurophysiological level, which was not possible for the traditional IS research that is based on self-reported data [1,2].

Although more IS researchers have recognized the advantages of NeuroIS and begun to engage in related research, there are still few articles published in top journals. Furthermore, the current research is rather fragmented, from which readers can hardly synthesize and apply meaningful conclusions and implications across contexts. To examine the development of NeuroIS research, Riedl et al. have published a review article on NeuroIS at the 2017 International Conference on Information Systems (ICIS) [3]. In the review, they focused on the following questions: Who published NeuroIS research? What kind of NeuroIS research was published? Which major thematic orientation was chosen by NeuroIS researchers? How was the empirical NeuroIS research conducted? Moreover, their review comprises publications from only 2008 to 2016, and to the best of our knowledge, there has not been a more recent one. Therefore, there is still a lack of reviews analyzing and synthesizing existing NeuroIS research from a more in-depth perspective recently. The goal of this paper is to fill this gap. Unlike Riedl et al. who reviewed all the NeuroIS research published in academic journals and in the proceedings of mainstream conferences, we only focus on the empirical NeuroIS research published in Science Citation Index (SCI) journals or Social Science Citation Index (SSCI) journals because these journals with high academic quality are important for the development of IS. We believe that such a targeted review is of benefit for research progress in NeuroIS.

This paper is structured as follows. First, we introduce the definition and reference discipline of NeuroIS. Second, we explain the method used for finding NeuroIS studies. Third, we put forward an integrative framework based on stimulus–organism–response theory in order to understand the research status of NeuroIS as an emerging field based on our analysis of collected articles. Fourth, we review the collected articles and summarize their key findings in order to provide an overview of NeuroIS studies. Finally, we discuss this study's research implications, future research opportunities, and its limitations.

## 2. Definition and reference discipline of NeuroIS

### 2.1. Definition of NeuroIS

The concept of NeuroIS was first proposed by Dimoka, Pavlou, and Davis at the 2007 ICIS, advocating the application of theories, methods, and tools of cognitive neuroscience to the research of IS [4]. Based on the understanding of the nature of NeuroIS, Riedl and Léger gave a more complete definition, claiming that NeuroIS is an interdisciplinary research field that relies on knowledge from other disciplines such as neurobiology and engineering. They also pointed out that NeuroIS can contribute to deep understanding of the design, development, use, and impact of information technologies, and thus help practitioners to design and develop IS [5]. According to the definition above, we can conclude that NeuroIS is a research field in which neuroscience theories and tools are used to better understand IS phenomena.

Since the concept of NeuroIS was put forward, a number of NeuroIS studies have been published [5]. Moreover, in order to demonstrate the progress in NeuroIS research and to provide a communication platform for NeuroIS researchers, two leading IS journals (i.e. *Journal of Management Information Systems* and *Journal of the Association for Information Systems*) have published special issues focusing on NeuroIS in 2014. It is evident that NeuroIS research has begun to receive more attention from the academic community.

### 2.2. Reference discipline of NeuroIS

While cognitive neuroscience is the main reference discipline of NeuroIS [1], reference disciplines of NeuroIS include neuropsychology, neuroeconomics, decision and social neuroscience, neuromarketing, consumer neuroscience, neuroergonomics, affective computing, brain–computer interaction, engineering, computer science, as well as biology and medicine [5]. Cognitive neuroscience is a discipline that seeks to explain "how the brain works, how its structure and function affect behavior, and ultimately how the brain enables the mind [6]". Existing cognitive neuroscience knowledge can reveal underlying brain activity involved in psychological processes, thus accelerating the research progress of IS and establishing a novel and distinct foundation of theories and methods for IS research [1].

The enlightenment of cognitive neuroscience to IS research can be illustrated by the research advancement of the Technology Acceptance Model (TAM) as a typical example. TAM is a theoretical model used to explain, predict, and influence information technology adoption. Despite the success of TAM++ proposed by Venkatesh et al. [7], its explanatory power is not perfect, and it is becoming more and more difficult for IS researchers who use self-reported data to gain new insights into technology acceptance. However, some NeuroIS researchers who use the theories and methods of cognitive neuroscience to study technology acceptance issues have advanced knowledge in this area to some extent [8]. For example, Dimoka and Davis revealed the neural mechanisms behind technology acceptance by identifying the brain regions that users activate when they interact with websites of varying degrees of usefulness and ease of use [9]. They claimed that perceived usefulness seems to be a multidimensional construct because it has three components; perceived ease of use seems to be a unidimensional construct because it locates in one part of the brain that is related to cognitive function. Dimoka and Davis' study gives people a deeper understanding of TAM constructs by exploring their nature and dimensions.

## 3. Literature identification and analysis

In order to collect empirical NeuroIS articles for our literature review, we employ a systematic approach which comprises several steps, including proposing research questions, selecting data sources, providing search terms, developing selection criteria, and

**Table 1**
List of journals with two or more NeuroIS articles.

| Journal | Studies | Number |
|---|---|---|
| *Computers in Human Behavior* | [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37] | 28 |
| *Journal of Management Information Systems* | [38], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49] | 12 |
| *Journal of the Association for Information Systems* | [50], [51], [52], [53], [54], [55], [56], [57], [58] | 9 |
| *MIS Quarterly* | [59], [60], [61], [62], [63] | 5 |
| *Decision Support Systems* | [64], [65], [66] | 3 |
| *Information & Management* | [67], [68] | 2 |
| *Electronic Commerce Research and Applications* | [69], [70] | 2 |
| *Electronic Commerce Research* | [71], [72] | 2 |
| *IET Intelligent Transport Systems* | [73], [74] | 2 |

conducting the review. Then, according to the collected articles, we put forward an integrative framework, analyze the results, and discuss the findings. This method is consistent with the work of Alam et al. [75] and the work of Zhang and Benyoucef [76].

### 3.1. Research questions

The primary research question of this paper is: "What does existing NeuroIS research published in SCI/SSCI journals mainly focus on?" This primary question can be divided into the following three research questions from the perspectives of theory logic, research topic, and research method:

RQ1: In terms of theory logic, is there a theory framework in which the key variables, dimensions, and relationships in the existing NeuroIS research published in SCI/SSCI journals can be synthesized?

RQ2: In terms of research topic, what are the main themes of the existing NeuroIS research published in SCI/SSCI journals?

RQ3: In terms of research method, which measurement instruments and subject populations have been used in existing NeuroIS research published in SCI/SSCI journals?

Compared to the review of Riedl et al. this paper focuses only on the studies published in SCI/SSCI journals, specifically more recent studies. At the same time, this paper tries to form a theory framework that integrates the previous paper and covers the key variables, dimensions, and theory relationship in relevant studies. Furthermore, the research themes and research methods are also investigated in this paper.

### 3.2. Data sources

We search for articles published in SCI/SSCI journals through the academic database Web of Science. The first reason why we focus on SCI/SSCI journals is that publications in these journals often receive widespread attention from researchers, and the second reason is that SCI/SSCI is often used as an indicator of academic quality [77]. In addition, the approach of using the SCI/SSCI journals as data sources has been used by previous scholars such as Moh [78], which indicates that this review protocol is sound.

### 3.3. Search terms

Following the work of Riedl et al. [3], we not only use the generic terms representing the field as a whole such as "NeuroIS", "Neuroscience", and "Nervous system" for our literature search, but also use the neuroscience tools terms such as "electroencephalography/EEG", "functional Magnetic Resonance/fMRI", "eye tracking", "electrocardiogram/ECG", and "hormone". The search start on January 2008, following the emergence of the concept of NeuroIS in December 2007 [4], and end in September 2019.

### 3.4. Selection criteria

During the process of selecting relevant articles, we examine the title, abstract, and the content of each article manually and follow the three inclusion criteria: (1) empirical research, (2) researching issues in the field of IS (i.e., information systems that use data to solve problems), and (3) using theories or tools from neuroscience. Through the literature selection process, we reflect on articles published in SCI/SSCI journals with empirical evidence regarding what current NeuroIS articles focus on.

### 3.5. Conducting the review

Based on the criteria above, we collect a total of 78 articles after excluding unqualified articles such as research commentaries, conceptual papers, guideline papers, and special issue editorials. Table 1 presents a list of 9 journals with two or more NeuroIS articles, which suggests that these journals are interested in publishing NeuroIS articles. As shown in Table 1, the three journals with the largest numbers of NeuroIS articles published are *Computers in Human Behavior* (n = 28), *Journal of Management Information Systems* (n = 12), and *Journal of the Association for Information Systems* (n = 9). In addition, 13 journals such as *Information Systems Research*, *European Journal of Information Systems*, and *Business & Information Systems Engineering* have published one NeuroIS article each [79–91]. The journals that publish NeuroIS articles are distributed in the fields of psychology, computer science, information systems, information science, library science, transportation science, management, business, etc.

## 4. An integrative framework for NeuroIS research

In this section, we consider the first question: Is there a theory framework in which the key variables, dimensions, and relationships in the existing NeuroIS research published in SCI/SSCI journals can be synthesized? In order to answer this question and synthesize the research findings of various articles, an integrative framework is proposed based on the stimulus–organism–response theory.

### 4.1. Theoretical background

Considering that NeuroIS studies enable scholars to measure biological data indicative of human psychological states and capture subconscious events behind human behavior [92], it can clarify the relationship between specific stimuli and user responses in IS contexts from the perspective of users. Thus, applying the stimulus-organism-response (SOR) theory to explore the research questions in existing NeuroIS research is appropriate. The SOR theory posits that various aspects of the environment can act as stimuli (S), which have impacts on people's internal state (O); people's internal state can affect their behavioral responses (R) in turn [93]. In the NeuroIS research context, IS environmental factors are external stimuli that can affect users' psychological reactions, and these psychological processes or internal states will then prompt users to form intentions or perform behaviors.

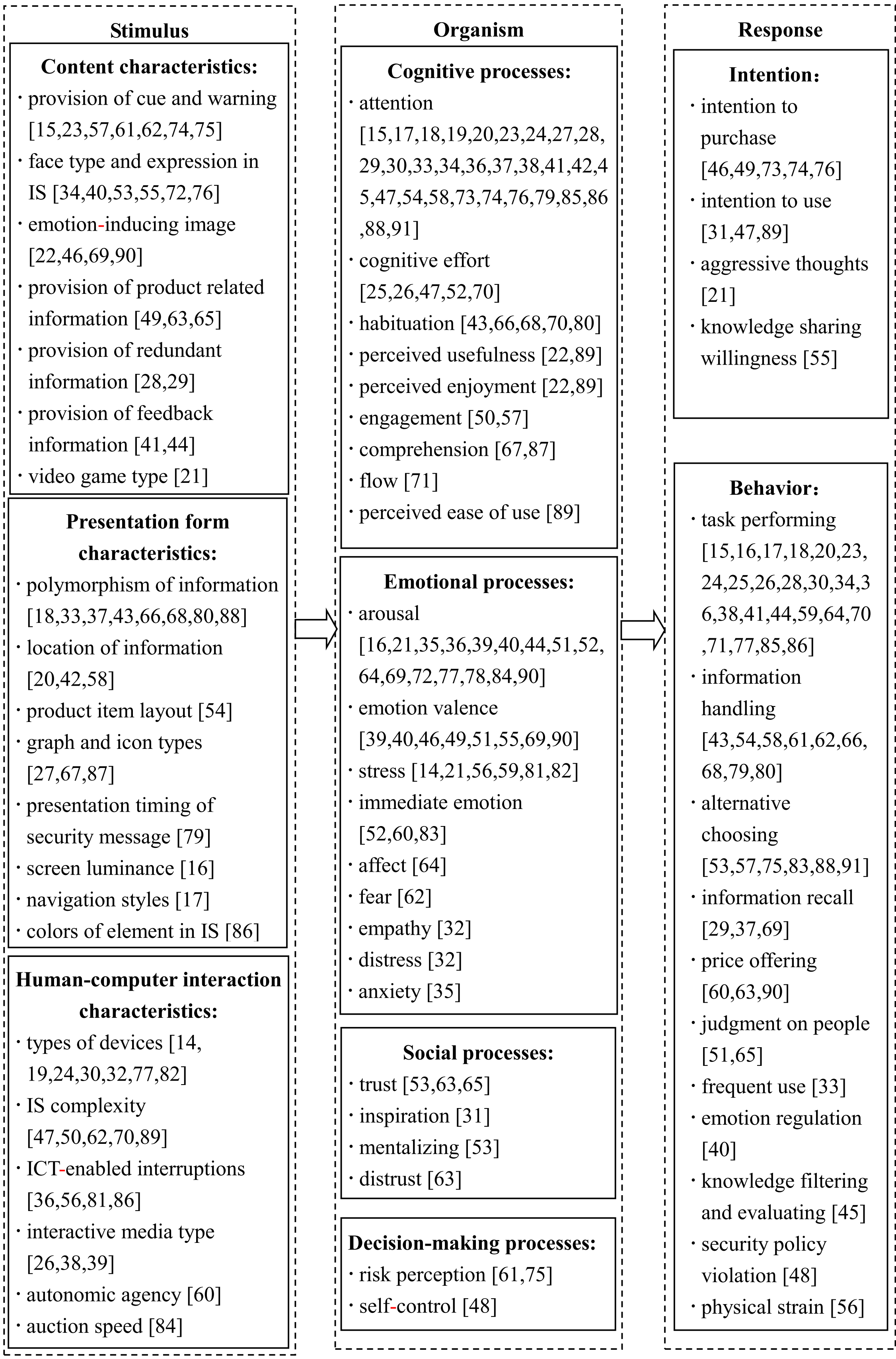


**Fig. 1.** Integrative framework for NeuroIS research.

### 4.2. Integrative framework

Psychological process variables are mentioned in each of the collected 78 articles, and these psychological process variables can serve as organism factors. Following the research published in *Information Systems Research* by Dimoka et al. [1], we classify the organism factors discussed in the 78 articles into four categories: cognitive processes, emotional processes, social processes, and decision-making processes. Cognitive processes such as attention, cognitive effort, and habituation reflect how people understand the nature of objective things and the relationships among objective things. Emotional processes such as arousal, emotion valence, and stress reflect people's attitudes toward objective things. Social processes such as trust, inspiration, and mentalizing reflect how people interact with others. Decision-making processes such as risk perception and self-control reflect how people make decisions.

In our framework, we summarize the antecedents of psychological processes in NeuroIS research. These antecedents are stimulus factors, and they have impacts on organism factors. Based on the analysis of the collected 78 articles, we find that content characteristics, presentation form characteristics, and human–computer interaction characteristics are important stimuli to affect users' psychological processes when they are using IS.

There is a great deal of previous IS research that has taken intention and behavior as key dependent variables [94]. Similarly, in the collected articles, the dependent variables or response factors are always related to intention and behavior. Thus, we classify the response factors into two categories. One category includes factors reflecting user's intentions, and the other includes factors reflecting user's behavior.

In summary, based on the analysis of the 78 articles, we put forward an integrative framework on the existing NeuroIS research published in SCI/SSCI journals. As shown in Fig. 1, of the stimulus factors, provision of cue and warning, face type and expression in IS, polymorphism of information, types of devices, and IS complexity are most widely investigated in view of their important roles in IS use; of the organism factors, attention, cognitive effort, habituation, arousal, emotion valence, and stress are most concerned by NeuroIS researchers; of the response factors, intention to purchase, task performing, information handling, and alternative choosing are most widely examined.

## 5. Detailed analysis of existing NeuroIS research

To present the existing NeuroIS research in more detail and answer the remaining two research questions about research topic and research method, we systematically review the existing studies. Each paper was put into a category according to the classification of their organism factors to guide the literature review. As shown in Fig. 2, cognitive processes (44 papers, 56.4%) and emotional processes (27 papers, 34.6%) have been investigated more often, while social processes (4 papers, 5.1%) and decision-making processes (3 papers, 3.8%) have been examined less often. Next, we respectively discuss the NeuroIS research in the four categories. To present the main themes of the existing NeuroIS research published in SCI/SSCI journals, the measurement instruments and subjects that have been used in existing NeuroIS research published in SCI/SSCI journals, we list the topics, main findings, measurement instruments, and subjects of some typical NeuroIS research in the following sections.

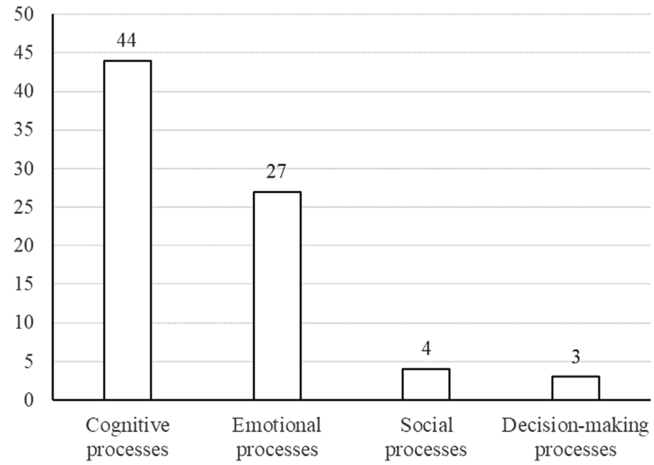


**Fig. 2.** Number of the literature in different categories.

### 5.1. Cognitive processes

In the 78 articles reviewed, cognitive processes are most often focused on. In this category, five main topics have emerged. First, as efficiency of IS use plays an important intermediary role between organizational investments and corresponding benefits [95], some NeuroIS scholars examined which IS elements can lead to high task performance based on individual's cognitive processes. For example, Liapis aimed to identify physiological inefficiencies between human and machine by joining observations in human cognition, neuroanatomical structures, finite state machines, and their associated relationships, and they found that voice-based email is better than Outlook-based email in terms of efficiency [22]. Second, as NeuroIS research has the potential to reveal individuals' cognitive-related neural mechanisms such as the attention distribution mechanism, some NeuroIS researchers have tried to learn how to improve the attractiveness of IS features. For example, by examining the dynamics underlying attention distribution of consumers when they are searching online, Ahn et al. claimed that placing an advertisement amid search results leads consumers to allocate attention more evenly and prompt them to pay attention to more product options [38]. Third, users' security interactions with technology are considered very important, and the issues about how to ensure users' information security and personal security based on individual's cognitive processes has received widespread attention by NeuroIS researchers. For example, based on habituation theory, Anderson et al. found that people's response to a repeated warning decreases because of habituation, but polymorphic warnings can reduce this decrease [39,64,80]. Fourth, the success of modern IS is based not only on its self-contained functionality, but also its hedonic user experience [96]; thus, user experience in IS is also a concern of some NeuroIS scholars. For example, based on the cognitive theory of multimedia learning, Zhou et al. explored how the presentation of cognitive learning aids affects the learners' perceived usability and improves their learning experience online [29]. Fifth, some NeuroIS researchers have explored individuals' cognitive processes during IS use to understand whether and why individuals decide to adopt a given IS. Technology adoption has been one of the most extensively researched areas in the IS domain [97]. Traditionally, IS researchers used self-reported data to explore the issue of IS adoption, but self-reported data are prone to many limitations such as the subjectivity bias, social desirability bias, and common method bias [1]. Employing neuroscience tools and methods can address these limitations by using more objective, less biased tools and helping researchers form new theories about human–computer interaction in order to better understand the IS acceptance model. For example, Guinea et al. explored the antecedents of perceived usefulness and perceived ease of use by users and made some contributions to IS adoption research [43] (see Table 2).

### 5.2. Emotional processes

Emotion is a critical component of people's experience when they interact with the environment [98], and the advent of NeuroIS means new and exciting methods for researchers to study, understand, and assess constructs of human emotions [1]. NeuroIS researchers mainly focus on seven issues in this category. First, in order to improve user experience, users' emotional state is usually considered into the IS work process [99], and NeuroIS researchers have conducted some studies about this issue. For example, in order to improve user experience during digital reading, Benedetto et al. investigated the influence of screen luminance and ambient illuminance on users' visual fatigue and arousal, which has practical implications for the implementation of adaptive brightness solutions [12]. Second, some NeuroIS researchers incorporated the user's emotion process into IS design activities in order to make the IS more effective. For example, based on the theory of image-text comprehension, Amir et al. found that providing an emotion-inducing image can help users to recall web-based information, thus improving their technology-mediated task performance. Third, some NeuroIS researchers have studied how to improve the attractiveness of IS features by revealing the emotional processes of people in the use of IS. For example, Wrzesien et al. studied the relationship between the physical similarity of avatars and the learning of emotion regulation strategies in teenagers, and found that an avatar that is physically similar to the participant is the most attractive one and has a significantly greater impact on the participant's emotional valence and arousal [36]. Fourth, the issue of technostress in IS has been examined by NeuroIS researchers. Human–computer interaction can lead to significant stress perceptions in users, which is called technostress [100]. Such stress has received much attention by IS researchers because it often impairs job satisfaction, organizational commitment, and continuance commitment [101]. The unconscious elevation of stress can be hardly measured by the traditional self-reported questionnaires [100]. However, IS researchers have demonstrated that physiological measures can offer better explanation and prediction, informing the measurement of technostress [102]. For example, Tams et al. used the triangulation approach to demonstrate the effectiveness of the physiological stress measure [55]. Fifth, the role of human emotions has been valued by researchers engaged in IS security-related research. For example, based on fear appeal theory, Warkentin et al. suggested that appraisals of recommended threat responses are more effective than appraisals of the threat itself in encouraging people to perform security behaviors [58]. Sixth, some NeuroIS researchers explored the issue of IS adoption by examining the users' emotional processes. For example, Gregor et al. found that positive and negative stimuli that induces emotion on websites can trigger users' emotional resonance, thus affecting the users' loyalty toward a website [42]. Seventh, some NeuroIS researchers examined the IS use consequences by revealing users' emotional processes. Although IS facilitates important aspects of contemporary life, it also leads to various negative consequences [103]. For example, Gentile et al. found that playing violent games is not good for elementary-aged children because it can lead to more aggressive thoughts [17] (see Table 3).

### 5.3. Social processes

In the 78 articles, we identify four constructs related to social processes: trust, inspiration, distrust, and mentalizing (prediction of other individuals' thoughts and intentions). In this category, only two topics, trust in IS and IS adoption, have emerged. First, determining who to trust and who to distrust is a major issue in IT-enabled impersonal exchanges [49,59], and this issue has received attention by some NeuroIS researchers. For example, Riedl et al. studied neural and behavioral differences between males and females when it comes to online trust issues, and found there are many differences between the male's brain areas that encode trustworthiness and the female's [61]. Second, not only cognitive processes and emotional processes, but also social processes such as inspiration can affect end user's intention to adopt IS, and this issue has been explored by some NeuroIS researchers such as Rodger. [27] (see Table 4).

### 5.4. Decision-making processes

Although decision makers can benefit from the use of emerging information technologies such as data analytics tools [104], data-driven decision processes will not completely replace individual's internal decision-making processes such as intuitive judgments [105,106]. Because of a limited number of empirical studies, only two topics, IS security and trust in IS, have emerged in this category. First, some NeuroIS researchers studied the issue of IS security by investigating users' decision-making processes. The crucial role of individual users in the security of IS has been widely recognized [107]. Given this reality, it is important to understand how users make decisions related to IS security. Compared with self-reported measures which are prone to certain bias that can undermine the validity of scientific findings, NeuroIS methods are better means to understand individual's decision-making processes and predict IS security behavior [57]. For example, by using EEG technique to investigate the questions in the criminology and information security fields, Hu et al. contributed to the expansion of research findings related to the role of self-control in the decision-making process [44]. Second, some decision-making processes that are involved in IS use activities can affect users' trust, so some NeuroIS researchers studied the relationship between certain decision-making process and users' trust. For example, by measuring the perceived risk of consumers viewing different reviews, Wang et al. found that product rating and sales volume are important factors influencing consumers' trust in products [71] (see Table 5).

### 5.5. Overall review

In terms of research topic, considering IS as systems that use data to solve problems, we sum up the topics of NeuroIS research according to the issues IS addressed. We found that existing NeuroIS studies mainly focus on three aspects: IS adoption before the IS is formally used; IS use-related issues, including IS use efficiency, IS security, attractiveness of IS feature, user experience in IS, trust in IS, and technostress in IS; consequences after the IS is used. Due to the limited research available, in the NeuroIS research of some topics (i.e., technostress in IS and IS use consequences), only one type of psychological process is involved. As shown in Fig. 3, IS use efficiency, IS security, and attractiveness of IS feature are the three most popular research topics. We believe that as relevant research increases, more topics will emerge, and research in each topic will cover more types of psychological processes.

In terms of measurement instruments, most existing NeuroIS studies used neuroscience tools to conduct research. In the past,

**Table 2**
Examples of NeuroIS research related to cognitive processes..

| Topic | Main findings | Measurement instruments | Subject | Study |
|---|---|---|---|---|
| IS use efficiency | Users have a higher success rate, less performance time, better satisfaction ratings, and greater user preference under linear navigation conditions than under hypertextual navigation conditions. | Eye tracking | Older adults | [13] |
| | Voice-based email incurs less cognitive load on people's prefrontal cortex and has higher operational efficiency compared to Outlook-based email. | EEG | General population | [22] |
| | Icons are different from logographical words in information systems when they are cognitively processed, and are less efficient than words when conveying meanings. | fMRI | General population | [87] |
| Attractiveness of IS feature | Icon composition and background have an impact on users' attention to the viewed icons. | Eye tracking | Students | [23] |
| | A user's attention resources can be rejuvenated by ads positioned in the middle of a search results listing. | Eye tracking | General population | [38] |
| | The product paired with a Duchenne smile draws more attention from users than a non-Duchenne smile, and smile intensity moderates the impact of smile type on the users' attention to product information in e-commerce systems. | Eye tracking | female | [72] |
| IS security | Polymorphic warnings can reduce habituation compared to conventional warnings. | fMRI | Students | [39] |
| | The timing of interruptions strongly influences the occurrence of dual-task interference in the brain, which in turn substantially impacts alert disregard. | fMRI | General population | [79] |
| | The habituation to safety messages (decreased response to a repeated warning) is caused by the eye movement-based memory effect. | Eye tracking | Students | [80] |
| User experience in IS | When presented dynamically, statically, or in a collapsed way, learning aids decrease in both frequency of use and the perceived usability in turn. | Eye tracking | Students | [29] |
| | Game complexity and game familiarity are two important factors to predict user-game engagement. | EEG | professional executives | [46] |
| IS adoption | Engagement moderates the effect of neurophysiological distraction on perceived usefulness; frustration moderates the effect of neurophysiological memory load on perceived ease of use. | EEG | Students | [43] |
| | Frontal asymmetry might predict users' perceptions regarding usefulness and ease of use; frontal asymmetry might also affect users' perceived playfulness. | EEG | Students | [89] |

Notes: EEG: electroencephalographic; fMRI: functional magnetic resonance imaging.

IS scholars have often used survey and interview data to conduct research. Although these methods can advance theoretical research, self-reported data are prone to many biases such as subjectivity bias, social desirability bias, and common method bias. Neuroscience tools can complement the traditional methods and overcome shortcomings of the traditional methods [2]. There are many neuroscience tools commonly used in NeuroIS research, according to the 78 articles studied. Those tools can be classified into the three categories, summarized by Riedl et al.: instruments to measure the central nervous system (CNS), instruments to measure the peripheral nervous system (PNS), and instruments to measure the hormone system [5]. In the collected articles, instruments to measure the CNS include functional magnetic resonance imaging (fMRI) and electroencephalography (EEG); instruments to measure the PNS include electrocardiogram (ECG), eye tracking, eye-fixation related potential (EFRP), electromyography (EMG), measurement of skin conductance (SC), measurement of heart rate (HR), and measurement of blood pressure (BP); instruments to measure the hormone system include measurement of salivary alpha-amylase (sAA). Based on analysis of the 78 articles, we found that eye tracking is the dominant tool in existing NeuroIS research.

In terms of research subjects, a few studies used special populations such as border guards, professional executives, professional software developers, and drivers as subjects. The most commonly used subjects in the 78 articles are students, then the general population, with most of the study participants being young people. For example, in the study of Jenkins et al. subjects ranged in age from 18 to 40 with a mean age of 23.7 [79]; in the study of Riedl et al. subjects were selected from the narrow age group of 30 to 35 [61].

**Table 3**
Examples of NeuroIS research related to emotional processes..

| Topic | Main findings | Measurement instruments | Subject | Study |
|---|---|---|---|---|
| User experience in IS | Both visual fatigue and arousal increase under high screen luminance. | Eye tracking | General population | [12] |
| | When watching videos presenting abusive behavior exerted to humans or robots, participants experience more emotional distress and show negative empathetic concern for the humans rather than the robots. | fMRI | General population | [28] |
| | Computerized agents can alleviate the immediate emotional intensity and overall arousal levels of users who are bidding in an online auction, thus affecting their bidding behavior. | ECG, SC measurement | Students | [56] |
| IS use efficiency | A NeuroIS tool was designed and implemented based on a serious game to make people aware of their emotional state and enhance their ability to manage emotions, thus improving their financial decision performance. | ECG | Students | [40] |
| | The neural correlates of emotion vary depending on whether the emotion-inducing image is relevant to the information provided or not, and these correlates are significantly related to recall. | EEG | Students | [65] |
| Attractiveness of IS feature | Observing an avatar physically similar to the participant has a greater impact on emotional valence and arousal, and induces more intense emotional states than when observing a neutral avatar. | EEG | Teenagers | [36] |
| | Users have higher arousal and process product information less deeply when facing the model's smiling facial expression paired with a direct eye gaze, compared to an averted eye gaze in the website. | Eye tracking | Students | [68] |
| Technostress in IS | ICT-enabled interruptions create stress, which then leads to physical strain, but enabling control can mitigate the relationship between stress and strain. | Hormones measurement | Students | [52] |
| | Physiological stress measurement is superior to self-reported stress measurement in predicting performance variance in computer-based tasks. | Hormones measurement | Students | [55] |
| IS security | Evaluation of recommended threat responses has a stronger influence on intentions to perform security behaviors than evaluation of the threat itself has. | fMRI | Students | [58] |
| | While driving, a user's interaction with a digital assistant system has a positive impact on arousal and alertness, thus maintain their operational safety. | Eye tracking, HR measurement | Drivers | [73] |
| IS adoption | Positive and negative stimuli that induce emotion on websites can trigger users' emotional resonance, thus influencing their intention to return to the website. | EEG | General population | [42] |
| IS use consequences | Compared to playing an exciting but nonviolent game, playing a violent video game leads to more aggressive thoughts for elementary school children. | Hormones measurement, HR measurement, BP measurement | Children | [17] |

Notes: ECG: electrocardiogram; SC: skin conductance; HR: heart rate; BP: blood pressure.

## 6. Discussion

The current empirical research in the field of NeuroIS is limited and rather fragmented. This study systematically reviews the literature of NeuroIS published in SCI/SSCI journals and presents an overview of current research. In this review, we identify a total of 78 articles through a systematic search. Then, we develop an integrative framework based on the SOR theory, and apply this framework to present what existing NeuroIS research focuses on. Further, we classify existing research into four categories according to the classification of their organism factors, and introduce these articles in terms of topics, main findings, measurement instruments, and subjects.

### *6.1. Implications*

The main findings of this literature review have several important implications. First, we put forward an integrative framework based on the SOR theory, which explains that IS environmental factors can affect users' psychological process factors, which further lead to their response factors. This framework can advance our knowledge of what existing NeuroIS research focuses on, as

**Table 4**
Examples of NeuroIS research related to social processes..

| Topic | Main findings | Measurement instruments | Subject | Study |
|---|---|---|---|---|
| Trust in IS | The brain areas that are activated by trust are different from the brain areas activated by distrust. | fMRI | Students | [59] |
| | The male's brain areas that encode trustworthiness are different from the female's. | fMRI | General population | [61] |
| IS adoption | Inspiration has a positive impact, through memory, on acceptance of digitized patient record technology. | Hormones measurement | General population | [27] |

**Table 5**
Examples of NeuroIS research related to decision-making processes..

| Topic | Main findings | Measurement instruments | Subject | Study |
|---|---|---|---|---|
| IS security | Self-control is a relatively stable individual characteristic that is related to human decision-making behavior; the levels of neural recruitment in both hemispheres of the brain of people with low self-control ability is lower than that of people with high self-control ability. | EEG | Students | [44] |
| | EEG can measure users' risk propensity and predict their security-related decisions; after users encounter a security incident, their disregard of security warnings decreases and their risk perceptions increase. | EEG | Students | [57] |
| Trust in IS | Product rating has a significant impact on risk perception while the combination of high rating and low sales leads to significant cognitive conflict. | EEG | Students | [71] |

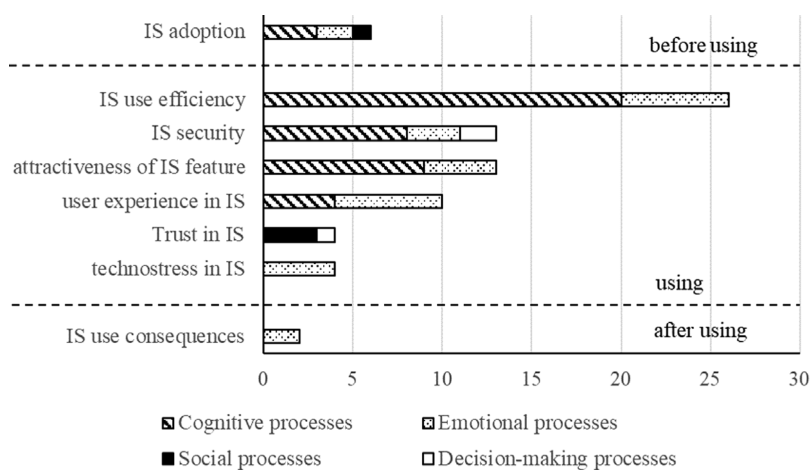


**Fig. 3.** Number of the literature in different topics.

well as lay the theoretical foundation for future research. Because NeuroIS is still an emerging field [2], it is necessary for IS scholars to understand the research status of NeuroIS. Our framework gives researchers who plan or execute NeuroIS research a coherent picture of the range of research issues in this field. In addition, by presenting the relationships among the variables, our framework can enlighten practitioners on how to affect users' mental processes by providing certain IS stimuli, which in turn affects the users' responses. As users' mental readiness is essential for IS success [108], understanding users' mental processes and relationships among mental process factors and other factors is beneficial for practitioners to make the IS more successful.

Second, we conduct a further analysis on the detail of empirical NeuroIS articles. Current NeuroIS research is too fragmented for scholars to infer meaningful and conclusive implications. To solve this problem, we offer an overview of the status of existing NeuroIS research and clarify the research topics, main findings, measurement instruments, and subjects in different categories. This can give researchers an overview of the NeuroIS field.

### *6.2. Emerging opportunities for NeuroIS research*

From this literature review, some future research opportunities have emerged. First, we have identified a wide range of stimulus factors, including content characteristics, presentation form characteristics, and human–computer interaction characteristics. These factors all belong to system characteristics. However, another important factor, organization characteristics, are ignored. In their IS success model, Petter et al. pointed out that organization characteristics such as IT investment, management support, and organizational size have direct or indirect impact on the success of IS [109]. The indirect effects are manifested in the influence of organizational characteristics on the success of IS by affecting users' psychological processes such as trust and pleasure. Because neuroscience tools and theories can offer great potential to investigate users' internal state during IS use and in different IS contexts [2], the influencing mechanisms of organization characteristics can be well explained by NeuroIS. In addition, future research can also explore the stimulus factors not covered in our integrative framework, and try to solve those problems that are difficult or impossible to solve in traditional IS research. Specifically, NeuroIS researchers should pay more attention to the new features of existing IS. For example, Geffen and Riedl encouraged scholars to make use of multidisciplinary knowledge to explore the effects of music stimuli, and to discuss how the theoretical findings can apply to IS contexts [110]. The impact of music embedded in the IS on human behavior is difficult to explicate, and the knowledge of NeuroIS may help scholars to generate new insights.

Second, most existing NeuroIS research concerns cognitive processes or emotional processes (see Fig. 2). This result is consistent with the results of Riedl et al. that only two fundamental processes (i.e., cognitive processes and emotional processes) have been investigated by the NeuroIS community, and social processes and decision-making processes have not yet fully explored by the NeuroIS community [3,5]. However, individuals' social processes and decision-making processes also play important roles during their IS use. A deeper understanding of these psychological processes can enhance the understanding of IS phenomena [1]. Therefore, we recommend that NeuroIS scholars give more attention to social processes and decision-making processes.

Third, many neuroscience tools can be used in NeuroIS research. However, in most IS research contexts, a "dominant tool" does not exist [2]. Therefore, in the future research, NeuroIS researchers need to make trade-offs when they choose research tools. As the CNS, PNS, and hormone system are closely related, future research can use different neuroscience tools to measure the same variable to triangulate different measurement methods.

Fourth, existing NeuroIS research is mainly based on the sample of students or younger general populations. Specific population subjects have seldom been studied. However, special populations have their own characteristics, and their IS use may be different from that of general population. One special population worthy of study is older adults. When it comes to IS use, the needs and concerns of older adults are different from that of younger adults because of their physical and cognitive deterioration [111]. Thus, the stimulus factors, organism factors, and response factors of older adults when they are using IS should be explored by NeuroIS researchers. In addition, some of older adults' psychological processes such as emotions and habits are difficult to capture with self-reported studies. However, these hidden processes can be identified by NeuroIS researchers using neuroscience tools. In the 78 collected articles, one study explored the effect of web navigation style on the attention of elderly users [13]. It is a good start for NeuroIS researchers to pay attention to the older adults. Because specific populations have their own characteristics, we believe NeuroIS studies can help IS researchers identify the psychological processes of these specific populations in order to design better systems for them.

### 6.3. Limitations

NeuroIS is still an emerging field, and the number of existing studies is limited. Since the goal of this paper is to provide an in-depth analysis of empirical NeuroIS research published in SCI/SSCI journals rather than conduct a comprehensive review of all articles in NeuroIS, we only focus on 78 empirical articles to explicate what NeuroIS research focuses on. However, because of the limited number of empirical studies in these top journals, we are not able to give a more finely drawn classification of NeuroIS research. But as more studies become available, a more comprehensive literature review is a task for future research. Another consideration is that the findings of this study was limited to the journals satisfying our selection criteria. Further research could expand the pool of articles and deepen the literature analysis.

## 7. Conclusions

This paper provides a systematic review of NeuroIS research. According to the analysis of 78 empirical NeuroIS articles, an integrative framework based on the SOR theory is proposed to present the current status of NeuroIS research. Moreover, insights are derived through a synthesis of the research topics, measurement instruments, and subjects of the 78 articles. We believe that our study will benefit the understandings of the NeuroIS field and provide some meaningful insight for future research.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgments

This work was supported by Key Projects of Philosophy and Social Sciences Research of Chinese Ministry of Education (No. 19JZD021), the National Natural Science Foundation of China (No. 71771210), and the Beijing Municipal Natural Science Foundation, China (No. 9182008).

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