Fusion of Cognitive Neuroscience and Human-Computer Interaction: A New Trend in Human-Computer Interaction Research

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Abstract: This paper, by means of literature and element analysis, discusses relevant literature in different fields such as cognitive neuroscience, human-computer interaction and brain-computer interface. Firstly, the development process of cognitive neuroscience is briefly introduced, and the evolution process of brain functional imaging technology is described. Secondly, the paper discusses the supporting effect of research results in cognitive neuroscience on human-computer interaction research. Then, the development of cognitive models for human-computer interaction research is described based on cognitive neuroscience and brain imaging technology, and some human-computer interaction researches from the perspective of cognitive neuroscience and brain imaging are briefly introduced.
Keywords: Human-computer interaction; Cognitive neuroscience; Cognitive model

1. Introduction

Most researchers have focused on some easily observed explicit behavior indicators in the field of human-computer interaction research so far, such as operation reaction time, task completion accuracy rate, keystroke speed, mouse click accuracy, eye line of sight changes, and so on. Few researchers have paid attention to the neural activity law and operation mechanism of user explicit behavior. In recent years, the technology and research results in this field have provided new ideas and methods for human-computer interaction researchers to uncover the cognitive neural mechanism behind user behavior, greatly expanding the field of human-computer interaction research and having a profound impact on many aspects of human-computer interaction research. Cognitive neuroscience is mainly focus on exploring the functions of brain and nervous system and the internal neural mechanism of people's explicit behaviors in daily life. Specifically in the field of human-computer interaction, relevant theories, research ideas and research methods of cognitive neuroscience can help human-computer interaction researchers to establish more accurate and powerful human cognitive processing models. These models enable researchers to evaluate the characteristics of human-computer interaction and predict the user's interaction behavior only through intelligent computation.

2. Development of Cognitive Neuroscience Research Technology

2.1 Basic knowledge of brain

Brain is a complex and sophisticated system composed of multiple subsystems, each of which is highly specialized to accomplish specific tasks. In recent decades, scientists have used various brain imaging techniques to explore the mechanism of brain operation. Based on the existing research results, scientists have constructed detailed topographic maps of the brain, linking different regions of the brain with specific cognitive functions. The brain is mainly divided into cerebral cortex and subcortical tissue. Subcortical tissue is older in system development and is mainly the basic functional area related to the survival of an individual. These functions include not only important aspects such as respiration, heartbeat, blood pressure, but also advanced psychological processing processes such as memory and

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decision-making. Cerebral cortex is a highly evolved brain tissue. It is the largest and most complex part of human brain tissue. It is responsible for complex psychological functions such as comprehensive sensory and motor processing, as well as advanced functions such as reasoning, planning, language processing and pattern recognition.

There are certain differences between the left and right hemispheres of the cerebral cortex. For example, most language functions are mainly located in the left hemisphere, while the right hemisphere is more related to abstract and spatial reasoning processing. Many studies have shown that the cerebral cortex can be further divided into separate regions responsible for different functions. For example, the occipital lobe region at the back of the head is mainly used for processing visual information. Temporal lobe region, along the lateral and lower regions of cortex, involves memory, pattern matching, language processing and auditory information processing, etc. The frontal cortex is involved in many functions, such as spatial reasoning, attention, planning, decision-making, reasoning, complex emotions, etc.

2.2 Development of brain imaging technology

Electroencephalogrphy (EEG) is a convenient and low-cost method in the research of brain function. EEG recording technology is used to record low amplitude electrophysiological activities of cerebral cortex by wearing electrode caps arranged according to certain rules (such as 10/20) on the head of the subject. Although EEG technology has some shortcomings (such as poor spatial resolution and high sensitivity to electrical noise), EEG has been widely used in the field of human-computer interaction research. For example, EEG recording technology is used to explore the changes in cognitive load and alertness level of operators in complex operating environments (such as airport air traffic management) with rapid real-time changes, or to evaluate the mental state of workers in monotonous environments (such as long-distance driving on expressways) such as arousal and fatigue.

Functional near infrared spectroscopy (fNIRS) is a brain imaging technology developed rapidly in the past ten years. FNIRS, like fMRI, is a non-invasive optical brain imaging technology that can detect hemodynamic response according to blood oxygen changes in cerebral cortex. FNIRS mainly uses near infrared light (wavelength is usually in the range of 760～850 nm) to measure the concentration changes of oxyhemoglobin (oxy-Hb) and deoxyhemoglobin (deoxy-Hb) after local neuron activation. Based on the physiological mechanism similar to fMRI, fNIRS is considered to be a reliable and effective method to detect activation of cerebral layer regions. Different from fMRI technology, fNIRS technology has the greatest advantage that it does not need to strictly control the experimental environment and needs very low environmental requirements. It allows subjects to move freely within a certain range and can also carry out multi-person synchronous research, which can meet the human-computer interaction research in various environments and is therefore one of the ideal choices for human-computer interaction researchers.

3. Human-computer Interaction Research Based on Cognitive Neuroscience

3.1 Cognitive neural basis of human-computer interaction

The process of human-computer interaction involves many psychological processing activities and is relatively complex, so this process not only involves the functions of different regions of the brain, but also includes the collaborative processing between different regions of the brain. A large number of researches on cognitive processes in cognitive neuroscience provide a cognitive neural basis for the research on human-computer interaction processes.

For attention processing, lateral temporal lobe and lateral frontal lobe are important areas in attention regulation. The lateral temporal lobe is mainly involved in regulating the attention caused by the current stimulus according to the existing knowledge, and the lateral frontal lobe is mainly responsible for processing the attention caused by the current stimulus itself. According to Fan et al, attention network is divided into three subsystems: alert, orientation and executive control [20]. Alert is to prepare for the upcoming stimulus, including thalamus, frontal lobe and parietal lobe. Orientation mainly refers to the selection of spatial location and objects. The brain regions involved include temporal-parietal joint region, frontal lobe oculomotor region, superior colliculus and other regions. Executive control is mainly a monitoring function to resolve conflicts between different information, involving the lateral prefrontal cortex and anterior cingulate cortex.

3.2 Development of human-computer interaction cognitive neural model

In recent years, human-computer interaction research has begun to focus on user experience, as usability is no longer the only important factor in interface design, People are increasingly interested in some interactive interfaces, not only because these products can support users to effectively achieve their goals, but also can maximize the positive emotional experience of users in the interactive process. Previous studies have shown that users tend to use or purchase products that can bring positive emotional experience to themselves.

In some early researches in the field of human-computer interaction, researchers tend to use cognitive model simulation instead of real human-computer interaction, thus reducing economic cost and time cost [23], which is a bit like simulation in the field of industrial and engineering research. These cognitive models are the models accumulated and summarized in the fields of psychology, industrial design, behavior analysis and human-computer interaction over the past decades. They can help researchers to better simulate the behavior of users in certain limited fields. The common operation mode is to use the established cognitive processing model to predict how a user (or a specific group of users) interacts with the interactive interface and performs specified tasks. However, many researchers have also criticized these models. They believe that when using these models, researchers cannot clearly distinguish most cognitive processing processes (including feeling, perception, thinking, etc.), but only adopt the hypothetical rule of "if …, then …", which will lead to these models unable to reflect the real psychological processing process of users.

4. Research on Brain-computer Interface and Human-computer Interaction

4.1 Development of brain-computer interface

With the development of cognitive neuroscience, links with information science, computational science and other engineering science become more and more close, and their interactions become increasly active. This interdisciplinary integration has led to a typical new field called brain-computer interface (BCI) which is the integration of cognitive neuroscience and human-computer interaction research. Brain-computer interface refers to the direct connection path established between human brain and external devices to realize information interaction between human and computer. In the past ten years, researches in the field of brain-computer interface have greatly promoted the development and application of implantable brain chips which can convert the user's nerve impulses into signals that can control external devices (such as manipulators and mechanical arms). Although the brain-computer interface technology is a remarkable progress for amputees or other disabled people, it is unlikely that healthy people will take the initiative to carry out dangerous brain surgery for simple human-computer interaction. However, in recent ten years, with the development of non-invasive neural recording technology, more and more researches have attempted to use non-invasive neural electrophysiological recording technology (EEG or brain imaging technology (such as near infrared spectroscopy brain imaging technology)) as a recording device for neural activity signals to connect with other external devices and directly control the external devices based on the neural activity signals. These non-invasive technologies can completely avoid the risks of implantable technologies and provide convenient and feasible approaches for human-computer interaction research based on healthy groups.

4.2 Cognitive basis of brain-computer interface

Early cognitive neuroscience research is mainly based on brain injury patients. By studying the selective loss of cognitive function caused by brain injury, researchers can understand the different cognitive functions responsible for or regulated by specific brain regions. With the development of brain imaging technology, researchers use the contrast between different types of groups to determine the activation of specific brain regions caused by specific cognitive activities. However, the disadvantage of this method is that due to the needs of laboratory experiment design, the cognitive activities completed by users basically exist in an isolated way and are completed in a carefully arranged and strictly controlled environment. Therefore, the ecological effect of this research is relatively low and the application scope of the research results is relatively small.

At the same time, it should be noted that there should be a certain difference between the brain activation mode caused by the cognitive activities of users in the real-world human-computer interaction process and the brain activation mode caused by this isolated and strictly controlled cognitive activities in the laboratory. Therefore, some researchers have developed wearable brain imaging systems suitable for use in the natural environment outside the laboratory. These wearable brain imaging devices can be combined with existing sensors in the natural environment to more conveniently link brain activities in the natural environment with tasks that trigger such activities. It should be emphasized that using this method, researchers can not only measure cognitive activities in more complex scenes than those constructed in the laboratory, but also study those cognitive processing processes that take a long time.

5. Conclusion

With the full launch of the China Brain Program, all walks of life will face a full and profound impact. At the same time, with the advent of the intelligent era, human-computer interaction is an important issue that enterprises, designers, researchers and users need to consider. At present, the development of cognitive neuroscience has provided comprehensive support in research ideas, research paradigms and research technologies for human-computer interaction research. It can be expected that in the next few years, cognitive neuroscience and human-computer interaction will be deeply integrated to achieve more high-value and high-impact results.

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