NeuroDesign: Making Decisions and Solving Problems Through Understanding of the Human Brain

Wei Liu(✉), Yanjie Jin, Binbin Li, Zhengfang Lyu, Wenjie Pan, Nan Wang, and Xin Zhao

Faculty of Psychology, Beijing Normal University, Beijing, China
wei.liu@bnu.edu.cn

Abstract. This paper introduces an emerging research field called NeuroDesign, which combines psychology, neuroscience, computer science, and design. It applies the cutting-edge cross-domain research methods to collect the designer's physiological data and psychological data, which has essential experimental support significance for this research field. Studies on NeuroDesign are based on neuroscience and use psychology methods and computer models to study design-related activities. The combination of neuroscience and design is an emerging field, and researching in this field has considerable significance.

Keywords: NeuroDesign · Design thinking · Neuroscience · Problem-solving · Decision-making · Psychology

1 Introduction

NeuroDesign, as an emerging discipline with research from psychology and neuroscience, is complemented by computer science models that apply to understand our design process and how to respond to designs. Neuroscience allows us to ignore the physiological mechanisms behind the perception of beauty in the process of understanding art and design. Cavanagh [2] studies how artists use it by examining the wrong light and shadows in paintings and other unrealistic depictions. The characteristics of the brain convey information economically. Hofel [9] showed that the stimuli of beauty and non-beauty showed significant differences 400 ms after the stimulus presentation. Both beautiful paintings and intricate artworks significantly activate the human cortex's frontal cortex. The beautiful object activates the bottom-up default system of the human brain in 360–1225 ms [5, 9].

Psychologists [10] explain people's perceptions of design and beauty from the perspectives of developmental psychology and psychoanalysis. Infants have the ability to perceive beautiful things in two to three months, and children have developed an aesthetic appreciation in primary school. In adolescence, individuals gradually develope an aesthetic evaluation with autonomy due to the formation of self-awareness. Psychologists [7, 10] also used projection techniques and pictures to compile famous projection tests, such as the Rorschach ink test and the theme test, from the perspective

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of psychoanalysis and applied them to treatment and evaluation. There are also a large number of case studies that prove that painting is an excellent way to deal with emotional conflicts, trauma, loss, and etc. when used in psychotherapy.

Theoretical models of computer science provides a theoretical framework. For example, the computational framework used by Munakata [14] provides a mechanical approach to understanding meme differences at a conceptual level, so that the results can be used for category learning, infants, amnesia, and developmental forgetting, as well as the development of flexible behavior. Goucher-Lambert and McComb [7] used hidden Markov models to discover brain activation patterns in the fMRI datasets associated with design.

The applied art of design includes industrial design, graphic design, fashion design, and decorative art that traditionally includes crafts. Gero [5] classify the research content of design activities: design process, cognitive behavior, and interaction, while the future direction of design creativity research includes design process, cognitive behavior, social interaction, and cognitive neuroscience measurement. Cognitive neuroscience is designed to be creative and is an open field of research that will study brain activity when the brain performs design tasks. It is one of the foremost research directions for NeuroDesign in the future.

The cross-disciplines are more relevant in these disciplines, including user experience, cognitive neuroscience, and computer aesthetics, which are also important subject areas and sources. The interdisciplinary user experience covers three parts: neuroscience, psychology, and design. According to Garrett [4], user experience includes user's experience of brand identity, information availability, functionality, content, and etc. Norman [15] extends user experience to all aspects of users and products. The application of the EEG and other brain measurement methods to the user's measurement of the first impression of the interface also allow us to open up new research ideas in the context of such disciplines and NeuroDesign [11]. Research results can, in turn, be applied to user experience domains.

Cognitive neuroscience is developed on the basis of brain neuroscience and cognitive science. Zeki [23] believes that 'art is also abstracted, and thus the way of working inside the brain is embodied'. Zeki officially proposed a new field of research, neuro-esthetics, to study the neural basis of artistic creation and aesthetics. Researchers use their brain function imaging analysis of brain neural activity to obtain substantial evidence about the brain mechanism of cognitive activity, making the research results more scientific and reliable [17].

Computer aesthetics is the most widely used in today's user interface design and interface design. The translators developed by Chen [3] extract visual features in UI images and encode the spatial layout of these features. Interface design involves a wide range of projects, from computer systems to automotive and commercial aircraft. Researchers [16] also incorporate user-centric design concepts into their own wearable EEG headset development projects.

2 Significance of This Research

By exploring the relationship between design and brain nerves, researchers are able to discover principles behind design guidelines to validate the design guidelines. Researches that based on neuroscience have found some new design guidelines. In the past few years, people have unconsciously used some effective means to modify people's perceptions, preferences, and choices about products. But if there is no guidance from neuroscience, they won't know how to make choices in so many categories of products and choose more potential products. For example, research has found that people don't like products that have images pointing to them or pointing downwards [1, 22]. Another study found that people prefer products or packaging that seem to smile at them. These are design criteria that have been discovered through neuroscience-supported methods [18]. In addition, neuroscience-supported methods are more widely used to design labels and logos. Neuroscience insights have also begun to provide a guide to the design of the business. In some cases, these insights will affect the design of the typeface in the near future [21].

In the process of designer designing activities, exploring the brain activities of designers, discovering some brain rules of design activities, and making the rules as designing a basis make design activities more able to promote cooperation and stimulate creativity. In previous studies, when studying designers' activities, the degree of activation of the brain, and various activities during the design were explored. For example, there are three different design tasks for designers and engineers, and then some instrument is used to detect their brain activity and discover the neural mechanism of the designer when they work independently [19].

The field of neuroscience and the field of design are both highly developed, but the study of the combination of the two is relatively rare, especially the research of designers' collaboration. It is a blank field. By studying the brain mechanism of the collaboration, this blank field could be filled. It is an interdisciplinary discipline with higher relevance extended from these disciplines. In this emerging discipline, the study of designer collaborative design is a blank field and a part of the later research that needs to be focused on neural design. Focusing on the brain activities of designers in the design process and exploring the brain mechanism behind the design guidelines, designers design a product that is people-centered. In this emerging discipline, the study of designer collaborative design is a blank field and a part of the later research that needs to be focused on NeuroDesign.

3 Methodology

NeuroDesign is able to draw on existing research methods and combine these research methods. It incorporates research methods in psychology and research methods in the interdisciplinary fields of neuroscience and other disciplines to study its own fields. See Fig. 1 for an impression.

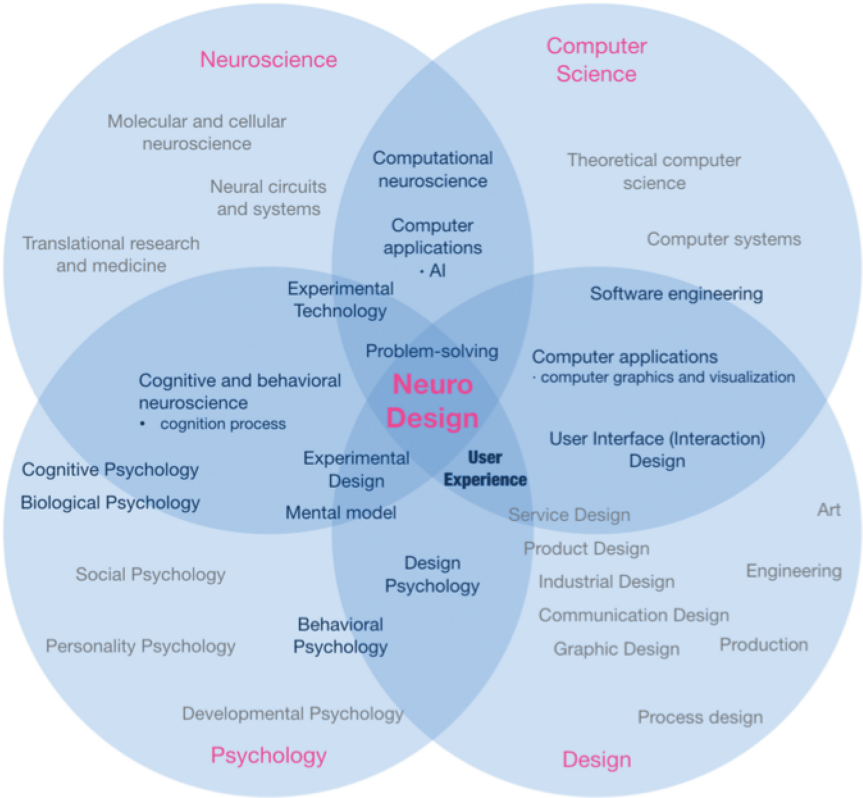

Fig. 1. The interdisciplinary research fields for NeuroDesign

Psychology research methods study the designer's behavior and brain activities, which is of great significance to this research field. The reaction time is one of the most commonly used reaction variables in psychology. It refers to the time required after the stimulation rather than when the reaction is performed. It is applied to the organism to the beginning of the obvious reaction, that is, the time interval of the stimulus-reaction. Any mental activity takes some time. Therefore, almost all psychological studies apply the principles and methods of reaction. Through this method, design behaviors can be initially studied and analyzed. The method is used to initially study and analyze the designer's design behavior, such as the reaction time of symbols or graphics are compared with non-designers, whether the analysis is significantly different. Functional near-infrared spectroscopy (fNIRS) uses the main components of blood to achieve good scattering of 600–900 nm near-infrared light, and obtain changes in oxyhemoglobin and deoxyhemoglobin during brain activity, so that calculate the amount of blood oxygen and blood volume changes in the region and monitor the functional activities of the cerebral cortex. This method is used to detect the degree of activity of the designer in the brain area of the design activity. DC-stimulated tDCS is directly stimulated by weak currents, causing temporary resilience of brain function excitation

or inhibition, or long-term regulation of cortical plasticity. Through this excitement or inhibition, researchers understand which brain areas are excited or inhibited when the designer completes the task.

In addition, NeuroDesign is a cross-disciplinary field of neuroscience and design. The research team refers to neuroscience and other research methods to select some suitable research methods. In recent years, neuromarketing has had a series of research and development. The discipline uses neurological methods to determine the driving force behind consumer choice. Similarly, NeuroDesign also uses neurological research methods to study the brain changes of designers to reveal the meaning behind their behavior in the design process. Functional magnetic resonance fMRI achieves brain function imaging by examining changes in the magnetic field of blood flow into brain cells, which gives a more precise structural and functional relationship and calculates whether these brain activities are related to attention, emotion, and memory processes, identity, and decision-making, etc. The technology's good spatial resolution detects which parts of the brain are activated by the designer when completing individual tasks and collaborative tasks. EEG is a safe and harmless brain scanning technique that measures voltage fluctuations from ion currents in neurons in the brain and has a very high temporal resolution compared to fMRI. By analyzing the EEG of a specific brain region, real-time changes in brain activity such as attention, emotion, memory process, and identity in the design process are obtained. Eye-tracking is a technique for tracking eyesight. During the experiment, the eye movement instrument will emit invisible infrared rays. By recording the surface reflection of the eyeball, the eyeball activity can be analyzed and accurately positioned, and the brain activity is speculated. The position of the gaze accurately reflects the position of people's attention. Through eye tracking, researchers analyze which elements the designer pays the most attention to when completing the design task. GSR is a technique for measuring the degree of skin electrical conductivity (often used as a polygraph) and is very sensitive to sympathetic activation and emotional excitement. This technique is used in conjunction with EEG to measure the excitement of a designer's work. The surface EMG signal is a one-dimensional time series signal from the muscle surface guided and recorded by the muscles of the neuromuscular system. The changes are related to the number of participating sports units, the movement unit activity pattern, and the metabolic status. Reflecting muscle activity status and functional status in real-time, accurate, and non-injury conditions, researchers find the difficulty by calculating the emotional changes in the design process by measuring the designer's changes in myoelectricity.

4 Research Settings

This article explores a variety of design methods, design principles, design theories, and applies them to all areas of the world as a high-level neurological activity. However, the neural mechanisms and psychological processes behind it are still not understood well. It is also unclear how many different levels of physiological mechanisms, cultural backgrounds, cognitive models, and subconscious minds that affect the design. Now, based on the nerves, using psychological methods and computer science models as an aid, design research has been greatly assisted. Studying the neural mechanisms in the design process,

general principles of NeuroDesign to practice will be found, exploring the brain mechanisms behind the design criteria, the specific design could be evaluated through neural research. The neural mechanism in user experience process makes the designer designing a more human-centered product. The brain mechanisms behind the design guidelines also provide theoretical support for the designer's design. Future research direction will focus on the brain activities of designers in the design process, especially the brain activities of designers in collaboration, or the similarities and differences between collaborative design and individual design in cognitive neural level. That is the further exploration of the relationship between neuroscience and design.

5 Possible Research Domains and Discussion

NeuroDesign is a combination of cognitive neuroscience and design. On the one hand, design researchers use the technology and research results of cognitive neuroscience to improve the development of this discipline, so as to make design, a discipline in the field of humanities and arts, more scientific, so as to eliminate and verify the existing differences and opposition between various theories. On the other hand, the field of design also provides cognitive neuroscientists with a new research direction and ideas, prompting more cognitive neuroscientists to engage in the field of design research. The integration of cognitive neuroscience into the design process is achieved through three parallel and continuous levels of analysis. The first is to analyze user experience or the neural mechanism in the process of product design. The second is to analyze the neural mechanism of designers in the process of design at the cognitive level. The third is to explore the brain mechanism behind the design criteria from the existing design criteria. This paper analyzes the research direction of NeuroDesign from the second angle. See Fig. 2 for an impression.

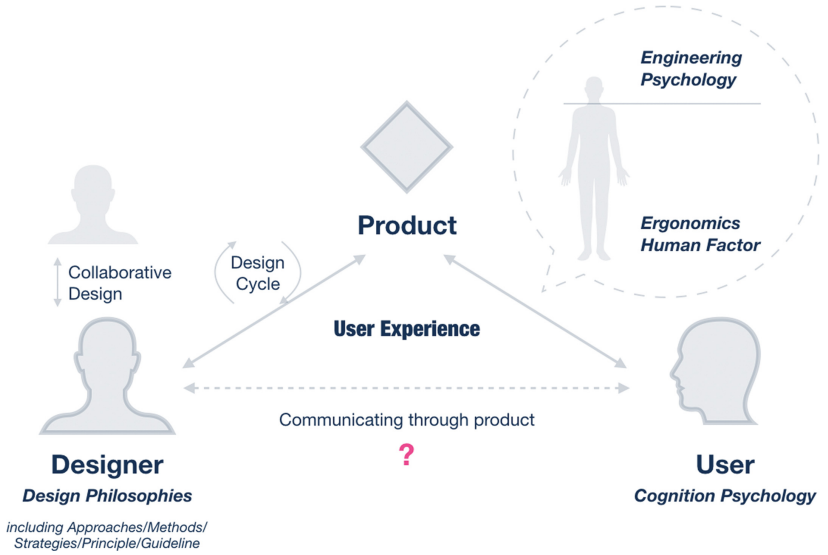

Fig. 2. The intertwined design process

The second research orientation of NeuroDesign is elaborated from two aspects, such as the research topic and the research object. First, as for the research topic, classic cognitive psychology research paradigms such as decision-making, problem-solving, and creativity are hot topics in the field of NeuroDesign. In terms of the research object, the design process is actually a process consisting of a series of unique events [6], from characteristic of design activity, independence and parallel, the design can be seen as a series of independent activities, therefore, from the perspective of the individual, the designer alone to carry on the design activity of neural activity. Concerning the integrity, cooperation and continuity of the design process, the relationship between human neural activities in the process of collaborative design is studied from the perspective of collaborative design. As far as the design process is concerned, its essence is the process of discovering problems, proposing solutions, choosing solutions, and designing outputs, which is analyzed from the cognitive level, including multiple cognitive processes, mainly including creativity, problem-solving, and decision-making. Both individual design and collaborative design are necessary to carry out the above cognitive process. Therefore, starting from the specific cognitive process and relying on the existing cognitive neuroscience research practice will be helpful to explore the research field of NeuroDesign.

5.1 Individual Design

Decision-making is a cognitive process, after which an individual decides on actions or opinions to be expressed in various choices according to individual beliefs or reasoning combined with various factors [8]. Every decision-making process aims to produce the final decision and select the final choice, which takes the form of an action or an opinion. Decision-makers are often faced with different options and choices, and some degree of uncertainty about the consequences of their decisions. The decision-maker needs to balance the advantages and disadvantages as well as risks of various choices in order to reach the optimal decision result.

Problem-solving is usually defined as a series of purpose-oriented cognitive operation processes, which is the most general form of thinking and the basic way for human beings to adapt to the environment and solve various problems in survival and development. The essence of problem-solving is a cognitive problem, and the process is described with the idea of information processing, and the influence of existing knowledge on this process can also be discussed with the idea of knowledge structure, and even the acquisition of knowledge in problem-solving.

Most psychologists now believe that creativity has two key elements, namely ‘novelty’ and ‘applicability’, which define creativity as the ability of an individual to produce new and unique ideas or products of practical value [20]. In a narrow sense, any thinking with novel and unique meaning to a specific thinking subject is called creative thinking. Over the past 10 years, many cognitive neuroscientists have used brain imaging technology with high spatial resolution and electroencephalography technology with a high temporal resolution to study and analyze the above three cognitive processes in different aspects, and achieved fruitful results, such as stages of processing in face perception: a MEG study [13].

5.2 Collaborative Design

For many people, designing behavior is an act involving others. For most people, the design process includes other members of their profession and members of other professions. At the appropriate time, each participant contributes what they can to a different area of expertise. The participants work together because each participant has specific expertise that contributes to the solution process. Therefore, the study on the cognitive neural process of each participant in the process of collaborative design provides practical and effective suggestions for the improvement of the efficiency of existing collaborative design and group design [12].

Collective decision-making studies how a group makes a joint action decision. The so-called joint action choice may be a process in which all parties participate in the same action for the common interests, just as a group of designers participates in the same design concept, or it may be a process in which all parties participate in the same action for different interests, such as the collaborative design process of designers, from different companies. Not only in the field of collaborative design, but also in other situations of collective decision-making, scholars at home and abroad have little exploration on the neural mechanism of group decision-making. On the one hand, the study of process organization involves many subjects such as decision science, psychology, mathematics, communication science, and sociology. On the other hand, people do not pay enough attention to it. In fact, a large number of collective decision-making questions need to be answered by the study of process organization.

Collective problem-solving, strictly speaking, and problem-solving in the psychology of originally refers to the cognitive and thinking activity. Still this kind of problem-solving thinking determines the behavior to solve the problem, researchers study the cognitive activities of problem-solving as individuals on the basis of the individual and collective, thinking, and behavior, research on the exploration to the collective problem-solving in the process of collaborative design as the research subject to explore and research. NeuroDesign is an emerging interdisciplinary research field combining cognitive neuroscience and design, aiming to provide more data support for the cognitive neuroscience of design, so that this field of humanities and arts are scientifically analyzed and interpreted. The current research focuses on decision-making and problem-solving in the individual design process or the collaborative design process. The field is growing fast, and there is plenty of room for growth. In the future, the research idea of integrating and separating research and combining bottom-up and top-down research will be helpful to establish a unified research paradigm in the field of NeuroDesign. The related research of NeuroDesign is of great significance to promote the scientization of design science and broaden the research dimension of cognitive neuroscience. Through analysis and discussion, researchers see that each research direction has its own advantages and disadvantages, which are applicable to different situations and purposes. Our article only discusses part of the research content and research methods, all of which have their own limitations. Therefore, both researchers and practitioners need to choose a more appropriate direction for specific research based on the understanding of various research models, according to their own research problems and research situations, and further enrich and improve in specific research practice.

6 Conclusion

NeuroDesign is a new research field of the fusion of psychology, neuroscience, computer science, and design. It is interdisciplinary. This emerging interdisciplinary research field aims to provide cognitive neuroscience data supporting design science to enable scientific analysis and interpretation of this humanities art field. Current research focuses on areas, such as decision-making and problem-solving, in both the individual design process and collaborative design process. This field is growing rapidly, and there is a wide space for its development.

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