Spatial Interaction Design for Children's Magnetic Resonance Imaging Examination Based on Embodied Cognition

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Abstract. To explore the spatial interaction design method for children's MRI examination based on embodied cognition theory, and to construct a design model suitable for the spatial interaction by combining the concepts of image schema and environmental affordance. This study adopted literature analysis and visual analysis tools to analyze research on embodied cognition at home and abroad, and explore the correlation between embodied cognition and spatial interaction design from the perspective of designing. Through observation and in-depth interview, this paper analyzed a series of problems encountered by children in MRI examination, and studied the applicability and feasibility of applying embodied cognition theory to spatial interaction design of children's MRI examination. At the same time, through field survey, users' journey map was drawn to probe into the hidden needs; finally, the feasibility of the theoretical model was verified by combining the design workshop and the design scheme, and the design thinking of children's MRI spatial interaction was put forward. When children undergo MRI examination, they have special psychological characteristics and behavioral needs and show high sensitivity to the space environment. By combining embodied cognition theory with spatial interaction design, four elements of interactive design for children's MRI examination space were obtained. The four elements are the matching degree of embodied cognition, the recognition degree of image schema, the operational degree of environmental affordance and the immersion degree of interactive experience. The design elements were verified by practical practice in workshops, which provides design thinking cases for the interactive design of children's MRI examination space.

Keywords: Children's MRI · Embodied cognition · Environmental affordance · Spatial interaction

1 Introduction

With the development and derivation of nuclear magnetic resonance imaging (MRI) technology, MRI witnesses more extensive clinical application in pediatrics [1]. However, MRI will be accompanied by obvious vibration and noise during examination, and

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it needs the absolute cooperation of examinees to be successfully completed, which is a great test for children. Besides, whether it will cause children's claustrophobia, tension, anxiety, resistance, resistance and other psychology in the process of examination is also a problem worth studying. Experiments prove that children with medical fear experience will reduce their compliance with medical care [2]. Apart from the problems in the examination process, the special environment of the hospital and children's strangeness, distance and oppression to MRI space may also cause negative psychological hints, which need further research and test. In the current medical system, each hospital has rare MRI system equipment. Except for a small number of children's hospitals, which have special MRI space for children, the rest basically share equipment and space regardless of age. In case of children's MRI, most of them adopt sedation and psychological intervention assistance [1], and seldom seek solution from the design perspectives of space environment, human-computer interaction, service experience, etc.

In this context, this paper attempted to explore the spatial interaction design for children's MRI based on interdisciplinary research, integrated embodied cognition theory, image schema and environmental affordance concepts, and combined children's physical and mental characteristics during MRI.

2 Embodied Cognition and Spatial Interaction

2.1 Embodied Cognition Theory A Subsection Sample

Embodied cognition is a revolutionary school developed in cognitive psychology since 1980s. It holds that human cognitive mind is formed in the interaction of brain, body and environment, and the formation of cognition is intrinsically related to the behavioral state of the body (i.e. embodied structure) and the empirical schema of physical activities [3]. Embodied cognition theory emphasizes the importance of physical activity participation when people carry out cognitive activities. Human cognition is formed when their physical activity experience matches their behavior patterns [4]. The basic process of cognitive composition is closely related to human physiological structure, and environment is an important factor in shaping human physical and mental structure. Therefore, cognition, as a product of interaction between human and environment, is the result of synergy among body, environment and activities [5]. The development of embodied cognition theory can be seen, which recognizes the role of body in cognitive activities and emphasizes that cognition comes from the interaction between human physical activities and environment, and undoubtedly provides a theoretical basis for reference for the design of specific spatial interaction that requires cognitive behavior participation.

In light of the development of embodied cognition theory, it is clear that since 1884, James and Langer have proposed that people's emotions are influenced by their physical changes. By 1945, Maurice Merleau-Ponty first proposed in his book Phenomenology of Body: The subject of perception is the body. Then, Gibson put forward the concept of functional affordance in 1979, which directly affected Norman's functional affordance in Design Psychology. Wilson put forward six viewpoints of embodied cognition in 2002 and John Baker studied the design framework of embodied learning in 2012. Many scholars are demonstrating and emphasizing the relationship and importance of

interaction between human cognition and physical environment, as shown in Fig. 1. In life, we can see such a phenomenon: people who have not ridden bicycles cannot understand how "balance" is controlled; children can recognize abstract mathematical concepts by counting their fingers.

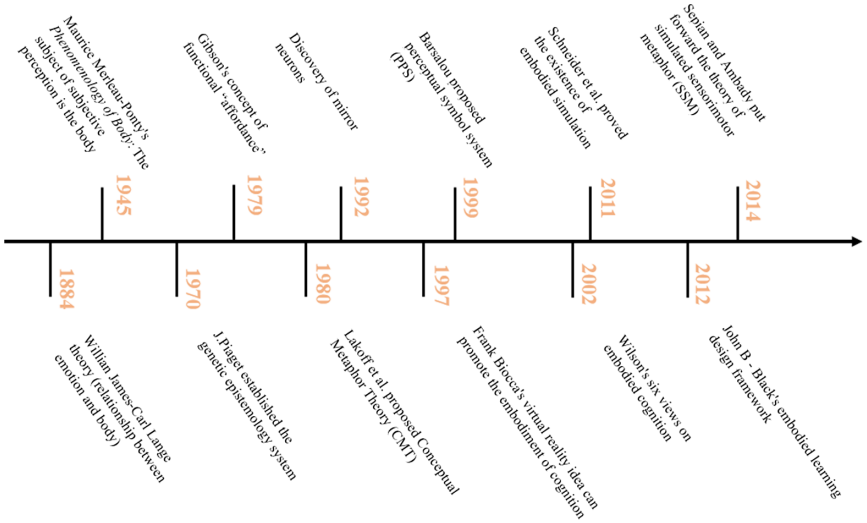


Fig. 1. Development of embodied cognition theory.

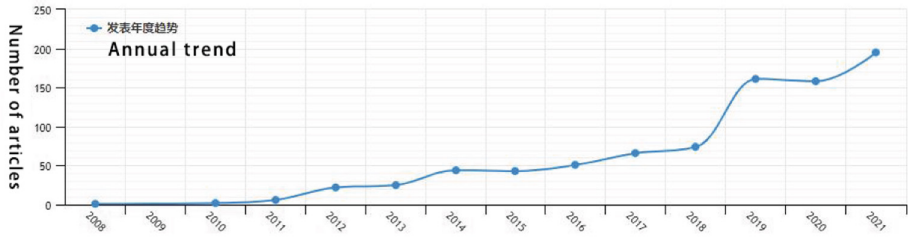
Historically, the research on embodied cognition theory has gradually shifted from metaphysical concept discussion to scientific verification based on empirical evidence [6]. A large number of research and experimental data prove that cognition is closely related to physical behavior and environmental situations.

2.2 Application of Embodied Cognition Theory in Design Field

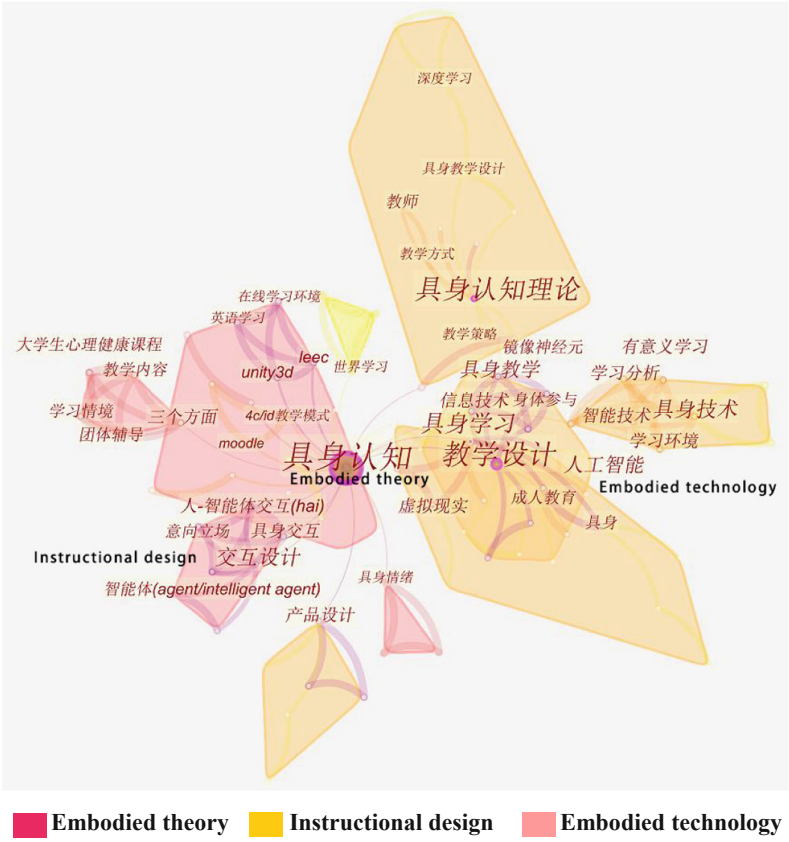
Related Theoretical Research

Since entering the 21st century, scholars at home and abroad have begun to study embodied cognition theory, and have made sound discussions on its academic source, concepts, practical application, etc. Meanwhile, some scholars started to study the application of embodied cognition theory in the field of design. On CNKI database, when searched with the keyword "design + embodied cognition", 659 Chinese documents of related research were found. After statistical visualization of the data, it can be seen that the number of related articles showed an obvious growth trend. Especially after 2019, many experts began to study the relationship between embodied cognition and interactive design, as shown in Fig. 2a. When we carried out literature analysis in CiteSpace, we used keyword co-occurrence visual analysis and merges synonyms (such as virtual reality and VR) to obtain an analysis map showing the relationship between keywords, as shown in Fig. 2b. The keyword clustering information and association shown in the figure, to a certain extent, reveal the theme and development of Chinese scholars in studying embodied

cognitive theory, focusing on three major aspects: related theoretical research, various types of instructional design, embodied interaction technology, etc.



(a)



(b)

Fig. 2. a. Publication trend of embodied cognitive theory literature (data source CNKI). b. Growth trend of published articles and co-occurrence analysis map (CiteSpace).

Through CiteSpace's analysis of the three clustering studies obtained from embodied cognition theory, we can know the research methods of embodied cognition in these aspects.

1. Theoretical research: Hypothetical experiment, experimental verification and cranial nerve forensics, etc. Scientists provide neurobiological basis for embodied cognition by hypothetical scenario, test subjects' embodied reaction based on the scenario, and then detect their neural mechanism through neuroscience and technology [7].
2. Instructional design: Experimental method, observation method, practice evidence-based and other means are adopted, and testees' perception of teaching methods and teaching environment are taken as the research subject. Then, certain guiding theories are teased out, and the research results are applied to actual teaching activities, proving that the teaching effect can be effectively improved [8].
3. Embodied interaction technology: It mainly uses computer technology and artificial intelligence. Due to the development of computer technology and artificial intelligence, people's behavior patterns can be predicted through big data algorithms in products. Human-computer interaction is becoming increasingly personalized, greatly enhancing users' use viscosity.

Application of Embodied Cognition in Design Field

The field of design research is always inseparable from the study of "people". The goal of design is always "people-oriented". People's functional needs, psychological needs, and emotional needs are all the categories to be studied in design. Whether it is space environment design, industrial product design, and visual communication design, it cannot be divorced from the study of people's cognition and behavior. In this sense, learning from embodied cognition theory is helpful to supplement the theoretical system of human cognitive behavior research in design research and further optimize the design effect. For example, Naoto Fukasawa put forward the concept of "unconscious design", which also pays attention to the influence of people's physical behavior experience on product design and meets people's hidden needs under unconsciousness. The behavior experience of pulling down the control fan is transferred to the playing control of the CD player, so that users can master the control mode without any learning cost, and can feel interesting from the interaction. The works thus produced resonate with most people emotionally.

The combination of embodied cognition and design can make design better meet users' experience and build a bridge between the material environment and users. Norman put forward the concept of Activity Centered Design ("ACD"), emphasizing that only by paying attention to and understanding behavior in design can product and interaction design be better carried out [9]. Tan Liang [10] proposed the prototype of human interaction mode in public space by studying the combination of embodied cognition and image schema, which provided a reference mode for the design of interactive devices placed in public space. Pen Bo [11], based on the research on embodied cognition, clarified the importance of participation and experience in children's education in museums, and deemed that children's cognition mostly came from physical experience, and effective use could deepen children's understanding of exhibits.

2.3 Relationship Between Embodied Cognition and Image Schema

Image schema, as one of the important concepts in cognitive linguistics, was first proposed by American linguists Mark Johnson and Lakoff in 1980 [12]. It refers to the fact that in the long-term life experience, people's behavior, mind and perception all have certain regular patterns and meaning schemas, which enable people to have meaningful and cognitively relevant experiences, and can understand and carry out reasoning learning [13].

Image schema is an abstract cognitive structure formed over time under the repeated interaction experience between human and environment [14]. Its schema determines the embodied expression of cognition and the formation of metaphorical language system. For example, the oral expression "he has great dreams" reflects the degree of "size" in the "nature" schema. Although the degree is a relatively abstract concept, it can affect our cognitive understanding and language system subconsciously. Another example is in behavior activities, when we see "stairs", we naturally associate it with "up and down" actions, which corresponds to the "space" schema. Therefore, the common image schema is the common behavior experience pattern that has been formed in the human brain, as shown in Fig. 3.

种类Type	意象图式 ImageSchema
空间（ORIENTATION）	上-下（UP-DOWN）、中心-边缘（CENTER-PERIPHERY）、远-近（NEAR-FAR）
容器（CONTAINMENT）	容器物（CONTAINER）、满-空（FULL-EMPTY）
历程（PROCESS）	路径（PATH）、起点-路径-终点（SOURCE-PATH-GOAL）、循环（CYCLE）
性质（ATTRIBUTE）	大-小（BIG-SMALL）、轻-重（HEAVY-LIGHT）、直（STRAIGHT）
作用力（FORCE）	推力（COMPULSION）、平衡（BALANCE）、阻碍（BLOCKAGE）
复数物（MULTIPLICITY）	部分-整体（PART-WHOLE）、接触（CONTACT）、连接（LINK）

Fig. 3. Partial classification of image schema.

It can be seen that although "image schema" and "embodied cognition" belong to different conceptual fields, they both focus on human cognition and mental habit models. The former discusses how language is affected by environmental states so as to make corresponding descriptive words; the latter explores how behavior is affected by environmental conditions, so as to make corresponding action inertia. Both of them explain that various interactive behaviors between people and things and between people come from cognition, and cognition is closely related to environmental states. Combining the concepts of "embodied cognition" and "image schema" can provide a theoretical explanation of "motivation" for interactive design.

2.4 Environmental Affordance in Spatial Interactions

Gibson, an American ecological psychologist, put forward the concept of environmental affordance in 1979. In his book The Theory of Affordance [15], he pointed out that "environmental affordance is what the environment provides to animals, whether good or bad" and "the environment is the surface that separates matter from media, and animals live in media (air)". In the field of design, the earliest application of this concept appeared in product interface design. Cognitive scientist Norman's book General Design Rules

mentioned that "Affordance" was translated into "functional visibility" [16]. Affordance is the actual attribute that material provides for people to perceive, the basic condition for identifying its functional use, and an important signal for prompting its operability. Affordance theory plays a crucial role in design research and design practice, especially in the interactive design of specific space environments (such as hospitals, schools, gymnasiums and other public places), which is an important indicator for users to evaluate experience satisfaction. This paper mainly studied the design of MRI examination space environment for children, focusing on the psychological suggestion of physical space scenes (including instruments and props) for children, that is, the affordance of interaction between children and the environment in the context of medical space. If this "affordance" is used and transferred to the interactive design of children's MRI examination space to create a medical space that matches children's cognitive level and conforms to their behavior patterns, it is likely to transform the "negative" affordance of the original environment into "positive" affordance and ease their panic and anxiety.

Although the above three theoretical concepts belong to different research fields, they are all intrinsically related to the problems studied in this paper. Embodied cognition emphasizes the influence of human body behavior experience on cognition. Image schema expresses the schematic conceptual structure formed in the interaction between human and environment. Environmental affordance refers to how environmental conditions meet human subconscious needs. The organic integration of these three concepts can provide corresponding guidelines for the interactive design of medical space for children in the early stage of cognition, as shown in Fig. 4.

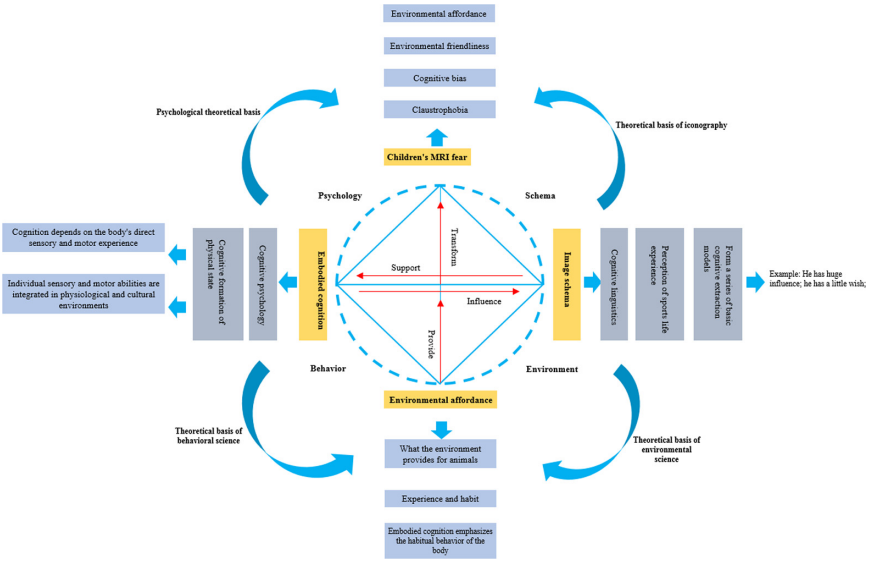


Fig. 4. Theoretical model of spatial interaction design of children's MRI examination based on embodied cognition.

3 Present Situation and Case Analysis of MRI Environment Design for Children

3.1 Status of MRI Environment Design for Children

Currently, most general hospitals in China have set up special pediatrics, but in the design of hospital space environment, the physical and mental needs of children, a special group, are often ignored. Even most professional children's hospitals focus on the superficial needs of children. They add playgrounds, increase bright colors, graffiti and cartoon patterns, etc. Basically, they are pursuing the contrast of superficial visual experience and space atmosphere, and seldom carry out designs from the perspectives of children's cognition, behavior patterns, physiological characteristics and emotional needs. Quite a few researchers explored the design of children's medical environment from the deep needs of children. For example, Peng Boxin [17], starting from the characteristics of children's behavioral psychology, proposed that the design of children's medical space should focus on "biological" needs to "physiological" needs, and hospitals should give more exclusive humanistic care designs to children. Liu Jie and Zhong Yue [18] proposed the best matching scale system for children's ward space design based on children's human factors and behavioral psychology. Besides, there are also studies on the space design of children's hospitals from the perspective of environmental behavior. For example, Rao Hongyue [19] studied the relationship between the affordance of the environment and children's behavior through long-term observation of users of Shenzhen Children's Hospital, and put forward strategies for the design of external public space of Children's Hospital, including barrier-free interesting pavement, flexible regional boundary, and distinguishing amusement space setting according to children's activity ability.

Moreover, some domestic medical experts, from their own professional point of view, studied the problems arising from children's MRI. Hu Yan and Lu Peng [20], professors of the First Clinical Medical College of Three Gorges University, started with the psychological problems of children facing MRI examination, sorted out five psychological problems such as fear, anxiety, resistance, fear of medical treatment and dependence, and put forward countermeasures for nursing intervention: strengthening communication with children, creating an adaptation process, encouraging parents to play their roles, weakening the fear of injection, etc. There are also medical experts who study the solution from the perspective of drug intervention. Peng Yinjuncheng and Tang Wen [1] carried out test on children patients from different ways of sedative drug use, and obtained the sedative intervention methods required by children of different ages.

It can be seen that the research on children's medical environment design still focuses on the design of the hospital's internal and external space environment, and rarely talks about the interaction requirements of special spaces. For example, there is rare research on the design of children's MRI space interaction, from an interdisciplinary perspective, and on comprehensive psychology, cognitive science and design.

3.2 Case Analysis

In foreign countries, especially in Europe and the United States, due to the early popularity of MRI and the fact that many manufacturers of MRI instruments are from Europe

and the United States, they have made multiple optimization schemes on the interaction of children's MRI. Especially from the design perspectives of spatial interaction and equipment improvement, a number of excellent cases have emerged that can be used for reference. As reported in the *American College of Radiology* (ACR) in 2019, Siemens and Marvel specially developed an interactive prop system for children's MRI examination for Will Cornell Medical Center of New York Presbyterian Hospital to solve children's fear feeling during MRI and reduce the use of sedatives. It was named "MRI-am-a-Hero" (Fig. 5). The system includes a set of specially adapted comic books, a Superman cloak, a miniature version of MRI instrument toy, dolls of Captain America and Iron Man, and a box of MRI education DVD simulating customs clearance games. Children first watched the educational content of DVD with their parents. The video fictionalized the process of a 10-year-old girl undergoing MRI examination, so that children had a certain understanding of the whole process before undergoing MRI examination. While waiting, children could play with instrument model toys and further know the equipment to be contacted for a while from a macro level. Meanwhile, they can also watch exclusive comic books, which adapt the story of Marvel comic characters Captain America and Iron Man cheering for children. During the examination, children can also hold toys all the time, which plays a good comfort role. Finally, after the examination, children can wear Superman cloaks, which is a reward for their "brave" behavior. The researchers found that after adopting such process, the proportion of outpatients aged 4–15 using magnetic resonance imaging (MRI) sedatives decreased by 5.6% [21].

Fig. 5. MRI-am-a-Hero.

From the above successful example, we can see that its design ideas all focus on children's cognitive ability and behavioral characteristics. According to the above theoretical viewpoints and case analysis, this paper teased out the corresponding conceptual design model, as shown in Fig. 6a. That is, the theme was set by embodied cognition (body behavior cognition: MRI process = Superman flight process), psychological suggestion was generated by image schema (nature state suggestion: track forward = Superman bravery), environmental affordance assistance was used (environmental condition provision: space transformation = hero game scene), and finally immersion degree of interactive process (MRI process = hero entry game) was realized, as shown in Fig. 6b.

From more cases, we can see the adaptability and applicability of the above conceptual design model. For example, Character Farms Company has developed a number of

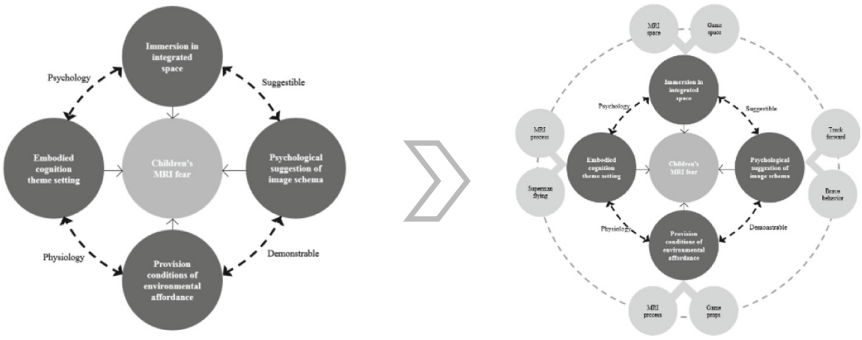


Fig. 6. a. A child MRI spatial interaction model based on embodied cognition. b. Case study using design model.

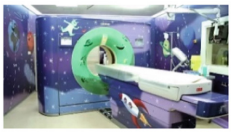
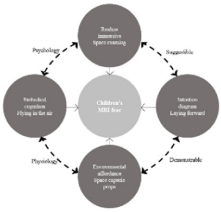
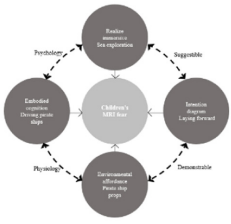
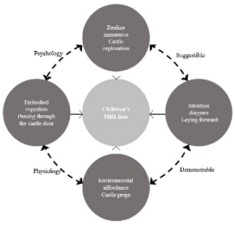
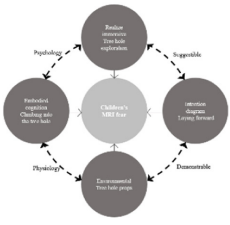
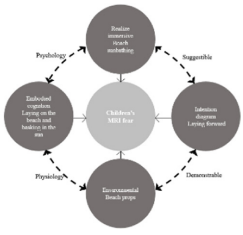
Themes	Space roaming	Submarine exploration	Pirate ships going to sea
			
Analysis of design model			
Themes	**Castle exploration**	**Tree hole adventure**	**Play on the beach**
			
Analysis of design model			

Fig. 7. Case study using design model.

overall solutions for MRI equipment and space interaction systems for children according to the needs of hospital customers. There are thematic interaction forms such as simulated space roaming, submarine exploration, pirate ship sailing, castle exploration, tree hole adventure, beach play, etc., which have been well received by doctors, parents and children. In light of the design strategy, it is not a simple pattern decoration, but a combination of children's embodied cognition and environmental affordance to obtain an overall spatial interaction solution. Its design idea is highly matched with the conceptual design model combed in this paper, as shown in Fig. 7.

4 User Survey and Design Workshop

4.1 User Survey Analysis

According to the theoretical combing and case analysis, after obtaining the spatial interaction design model for children's MRI, this study, supported by the Radiology Department of the First Affiliated Hospital of Sun Yat-sen University in Guangzhou, conducted many field surveys, and employed observation methods, in-depth interviews, user portraits, user journey maps and other methods for research and analysis.

First of all, after many field surveys and careful observation and recording of the whole process of children's MRI, it can be seen that children showed obvious fear and anxiety in the four steps of waiting before examination-preparation before examination-examination-examination-end. The specific behaviors are as follows: 1. Fidgeting and walking back and forth while waiting; 2. After entering the MRI testing room, they felt afraid and became dull; 3. Crying and asking for parents in the examination; 4. When the machine was running, it gave out strong noise; although children wore earplugs, they were still afraid and tossed and turned on the examination table; 5. Only after the examination did the children relax and become obviously active again.

After preliminary survey and observation, the process steps and intuitive problems of children's MRI were clarified, and two of them were interviewed in depth. Eight interview questions were put forward from three directions: intuitive feeling, cognitive understanding and hope vision, as shown in Fig. 8 for details. From the answers of children and parents, we can identify the following key points:

1. The overall experience and feeling is relatively negative. Due to the unfamiliar environment, the strong noise accompanied by the operation of the instrument, the high restriction on the body, certain claustrophobia, inconsistency with children's physical experience and other factors, children are prone to negative emotions. Thus, the MRI examination was of low friendliness;
2. The overall cognitive understanding is low. Children can't basically understand what MRI is. Even if doctors and parents give appropriate explanations, it is still difficult for children to understand. This cognitive deviation is beyond the scope of children's understanding and is one of the key reasons leading to their fear and anxiety;
3. It is hoped to change the status quo. In the process of in-depth interviews, both children and parents hoped to optimize and change the current situation. Especially in the space environment and interaction process, they all expressed their love and

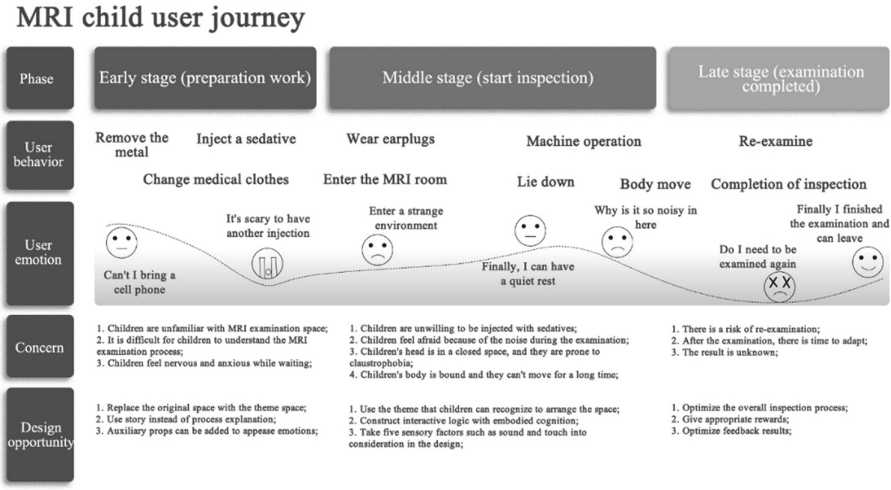


Fig. 8. Child MRI user trip diagram.

yearning for the displayed cases (six groups of schemes of Character Farms Company), and children can accurately recognize the theme and "play method" of the cases, and feel that anxiety and fear can be relieved.

At the same time, according to the preliminary observation and in-depth interview, based on the process of children's MRI spatial interaction, a user journey map was made, as shown in Fig. 9. Through the analysis of each node, the internal needs of users were deeply explored, the main behavioral characteristics and emotional fluctuations of children during the examination process were analyzed, and the concerns of children during the MRI process were identified. In the process line of "early stage (preparation work)-middle stage (start of examination)-late stage (completion of examination)", there are some behavioral points worthy of attention, among which the negative points are: injection of sedatives, entry into MRI room, machine noise and need to be re-examined. These negative emotions are directly related to children's cognition and physical feelings, which further confirms that the aforementioned conceptual models in this paper are highly matched.

To sum up, after field survey, observation records, in-depth interviews and user journey maps, we can see that the actual problems faced by users are similar to the conceptual model mentioned above in this paper, which is of great adaptability and applicability. Starting from embodied cognition, this paper combined image schema and environmental affordance, and constructed a spatial interaction design methodology suitable for children's MRI examination so as to improve the current situation to a certain extent, meet the deep needs of users, reduce the burden on doctors, and achieve a balance and win-win situation.

4.2 Design Workshop

In order to further verify the guiding significance of this design model for children's MRI spatial interaction design, this study used this design model as a guide to obtain scheme evaluation and feedback in the form of design workshop. The workshop invited ten undergraduates majoring in art and science and technology. The author first systematically introduced the design model, and divided these students into two groups, with five in each group. They were asked to take the Radiology Department of the First Affiliated Hospital of Sun Yat-sen University in Guangzhou as the carrier and children aged 3–10 as the design subjects, and adopted the model to design the scheme so as to alleviate children's fear and anxiety and enable children to clearly recognize the theme and interactive behavior. The two groups of participants finally completed two sets of children's MRI spatial interaction design schemes (Fig. 9 and Fig. 10). After many

Fig. 9. Design scheme of children's MRI space interaction with the theme of "space transfer warehouse".

arguments, the first group chose the "space transmission warehouse" as the theme and designed the scheme strictly according to the design model: From the perspective of embodied cognition, the theme (MRI process = space transmission)-image schema psychological suggestion (orbit forward = fantasy exploration)-environmental affordance (MRI equipment = transmission props)-immersive interactive experience (MRI space = space space) was designed. At the same time, the scheme also took into account the comprehensive sensory experience design combining visual and auditory factors, and conceived a customized VR glasses and earphone device, which played the video and sound of space roaming, so that children can completely immerse themselves in the content and forget their idea of doing MRI examination. The overall atmosphere of the final scheme was fantastic, the theme was clear, full of children's interest, and the integrity was high. It can attract children's attention, and change the coldness and seriousness of the usual MRI space.

The second group chose "time tunnel" as the theme, and also designed the scheme strictly according to the design model: From the perspective of embodied cognition, the theme (MRI process = time shuttle)-image schema psychological suggestion (track forward = crossing start)-environmental affordance (MRI equipment = shuttle props)-Realize immersion interactive experience (MRI space = time tunnel) was designed.

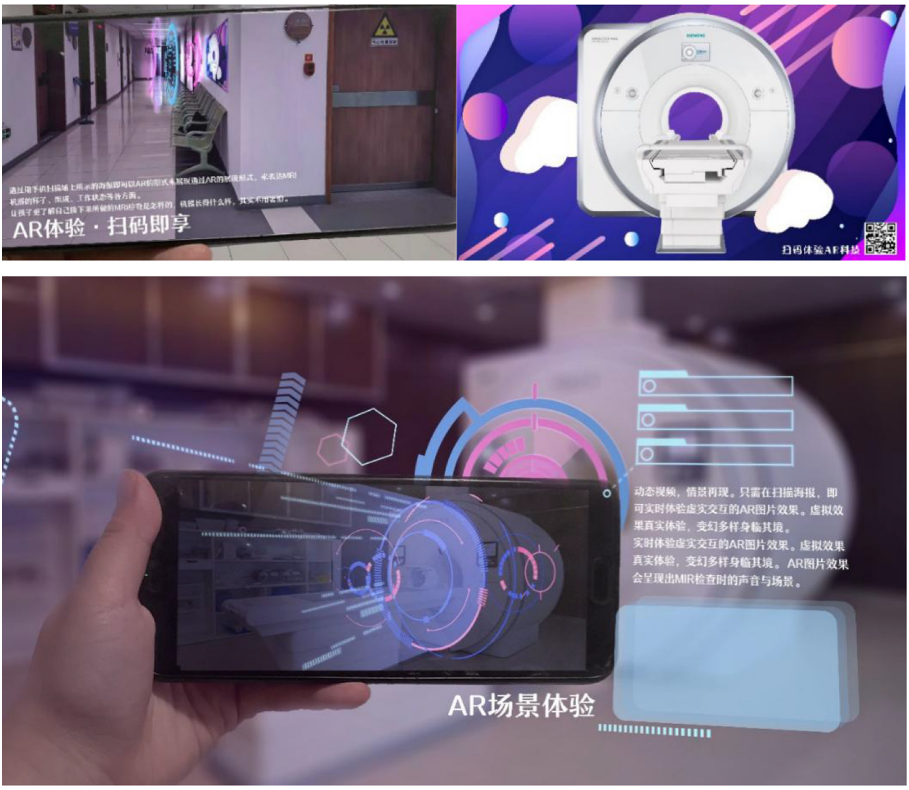


Fig. 10. Design scheme of MRI spatial interaction for children with the theme of "Time Tunnel".

This scheme not only fully considered embodied cognition to spatial interactive applications, but also took into account the digital way of realization. That is, AR (Augmented Reality) and projection imaging technology were used to realize the change of scene theme and the realization of interactive process. Such digital solution greatly reduces the implementation cost and the investment in hospital space equipment. When adults check in the same space, they only need to turn off the projection system to restore the scene, thus realizing the interaction of multiple scenes in one space.

5 Conclusion

With the continuous development and derivation of magnetic resonance imaging (MRI) technology, it has seen wider clinical application in pediatrics. However, due to its serious environment, cold instruments, strong noise, forced body, unfamiliar experience, unknown results, etc., children feel afraid and anxious, and even produce medical fear. The reason is the lack of design and development of MRI system specifically for children. Therefore, starting from children's cognition and behavior, this paper integrated embodied cognition, image schema and environmental affordance theory, and obtained a model based on spatial interaction design of children's MRI examination was obtained. Also, this paper put forward four elements of spatial interaction design for children's MRI examination. The four elements are the matching degree of embodied cognition, the recognition degree of image schema, the operability of environment and the immersion degree of interactive experience. As verified by field survey and design workshop, the design model method can effectively construct spatial themes and interactive operations that children can understand, and can alleviate children's fear and anxiety to a certain extent. Moreover, the design model is also applicable to the special spatial interaction of other children's medical treatment, and has certain mobility and guidance, which provides a reference for the design of special spatial interaction for children.

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