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Empirical Study on the Optimization Strategy of Subject Metro Design Based on Virtual Reality

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A three-dimensional simulation interactive virtual scene was established taking the theme subway in Chengdu and Guangzhou as the typical case, and the standard metro in Xiamen as the reference. An experiment was designed using virtual reality built-in eye movement equipment and following the principle of visual attentiveness. The conscious and unconscious visual behaviors of users were analyzed and the impacts of different design methods on user experience and behaviors were analyzed. This study extracted the key elements of the theme subway design and recombine them to compared the design of facilities at the same position but in different themes and the design of space interface at different positions but in the same theme. Moreover, optimization strategies were put forward for the design of theme subway space to enhance the availability of the design.

Povzetek: Predstavljena je virtualna študija za učinkovito predstavitev podzemnih kitajskih železnic uporabnikom.

1 The status of internal design of theme subway

According to the statistics of China's rail transit network, 24 of 30 cities which have subway have opened theme subway, and 69 themes are included [i]. Theme design refers to a design method of setting up a series of scenes or events in the form of visual creativity by means of narrative techniques to establish a transfer link with audience. Theme subway which applies theme design is taken as the material carrier of social and cultural information, which solves the problem of characteristic crisis of space [ii], makes people perceive the cultural atmosphere and connotation of a city or region, and enhance the identifiability of a city.

The current design of theme subway in China focuses on the publicity of theme, still in the initial stage. Design ideas of the internal space of subway is monotonous. The design ideas include texture design and design of three-dimensional modeling. Texture design means directly applying theme related picture materials on the wall surface of carriages. Design of three-dimensional modeling means transforming three-dimensional cultural model or plane cultural elements to three-dimensional models, taking them as facilities or decoration carriers, and endowing them with practical or decorative functions.

Wang Dawei from Shanghai Academy of Fine Arts proposed the theoretical model of space design of subway station which is a cube model composing of professional emphasis, design elements and subway space. The design should consider not only visual aesthetics but also the security, comfortability, economical efficiency and sustainability of metro space design [iii]. The design of theme subway needs to reduce the psychological pressure of passengers in the claustrophobic space from the psychological point of view and improve the visual comfort of passengers in the subway environment. As to the content of theme culture, the design should guide passengers to form short-term memory and information feedback. The current theme subway is mainly based on experience design; the good and bad efficacy are intermingled because of the lack of scientific basis and experimental verification.

2 Reflection of design of theme subway based on the principle of visual attention

James (1890) first proposed that the directivity and centrality of perception are the two basic characteristics of attention and only a few objects will be noticed at the moment when objects are sensed [iv]. It shows that attention has the role of screening. In the process of visual scene observation, the user's visual presentation is progressive and incomplete [v].When attention is focused on the perceived area, consciousness can capture the stimulation of interest in that area. Von Helmholtz (1925) and James (1890) put forward "where"and "what" [vi]."Where" is a view put forward by Vol Helmholtz. He focused on the relationship between eye movement and spatial position.

It means that involuntary attention is a fixation behavior which is based on individual experience or task objectives and controlled by consciousness or autonomous behaviors. "What" is a view put forward by James. He thought that attention is a mechanism with hidden inner. It is active and voluntary and relates to properties, significance and expectation of attention focus, involving information processing, refers to voluntary fixation behavior under an unconscious state. Short-term memory and even long-term memory will form when people use the attention of high-level cognitive ability.

Attention is an important psychological adjustment mechanism in the process of visual information processing, and it is not only related to individual cognition, but also influenced by emotional mechanism [vii]. In *Emotional Design*, Donald Norman proposed three levels of brain information processing, in which the instinctive level is the subconscious judgment determined by biological heredity (subconscious judgment of individual behavior), and the behavior layer is a habit based reaction (based on the individual experience). They correspond to high level of attention (involuntary attention) and low level of attention (voluntary attention) respectively.

According to the above principles, when passengers enter a carriage, observation of the instinctive layer is firstly induced, and the attention is active and voluntary at that moment. If a certain area in a scene arises passengers' interest, the area will be perceived by the vision around the central fovea, and then more detailed content is perceived. The visual fixation area and time data of passengers in this state are obtained through first fixation time among eye movement indexes. First fixation time refers to early identification process of area of interest and sensitivity to processing difficulty of area of interest. Shorter time indicates that the region is easier to be concerned by users [viii]. The visual design features of the interest area inside the carriage were summarized. In addition, the involuntary attention of the behavior level is controlled by consciousness and autonomous behaviors. The scope of attention is very small; hence passengers perceive all the parts of the scene through continuous scanning. Whether the design of carriage induces the short-term memory of passengers can be analyzed based on the division of area of interest of heat map and retention time. Area of interest (AOI): It is usually used for design availability analysis. Some element of interface is isolated as a specific area or content for further analysis [ix]. Heat map refers to information visualization graph which presents eye movement data in the form of cloud picture [x]. It can intuitively present the area of interest of the subject and analyze the focus area and retention time. Retention time: retention time is a very good index for testing the degree of interest for a specified area of interest. Longer retention time means more interests of users on an area of interest [xi].

3 Necessity of virtual reality eye movement linkage experiment

In the past, the experimental research on internal design of rail transit was mainly based on rendering pictures and portable eye movement equipment. The maturity of the technology which combines head mounted virtual equipment with eye movement instrument in 2016 provides technical support for the accuracy of data and control of independent variables of such kind of study [xii]. Compared with the previous experiments, the advantages of the experiments which apply the new technology are mainly reflected in the following three aspects.

(1) Strong immersion in visual scene and more objective data

The visual scene is a three-dimensional simulation model with high preciseness, which restores the internal facilities, lighting, dimension sense of space and texture of the real scene; therefore subjects can obtain real experience in the virtual environment [xiii]. For example, in the course of the experiment, subjects try to grasp a handrail after entering the scene, which shows that the scene is very vivid and more objective eye movement data can be obtained. In the previous experiments, two-dimensional pictures were usually used as stimuli, and subjects cannot feel immersed, which affected the objectivity of data.

(2) Extraction of implicit data and recording while looking

The experiment of portable head eye tracker combined with pictures is very difficult for users to concentrate due to the large error of eye movement data and the small size of stimulon. The virtual reality scene can be observed in 360 degrees, and the subjects' perspective is large, which can not be constrained by the size of picture. It can collect the eye tracking data consciously and unconsciously (implicit) in the virtual scene in real time to perfect categories of data [xiv].

(3) Effective control of independent variables is beneficial to comparison

Design factors which can affect user experience include content of theme, shape design, area of pattern and position of decoration. Changes of variables in virtual eye movement experiments will generate different scenes; in this way, scene changes can be realized under no disturbance. It is beneficial for comparing reactive states of user experience and analyzing the relationship between variables and design. For example, visual attention of subject will transfer when the color saturation inside subway carriage is too high.

4 Experimental design

Taking the theme subway in Xiamen, Chengdu and Guangzhou as the research subjects, this study established a three-dimensional simulation interactive virtual scene. The eye movement of users in the scene was recorded. The influence of different designs on user experience was compared and analyzed based on the

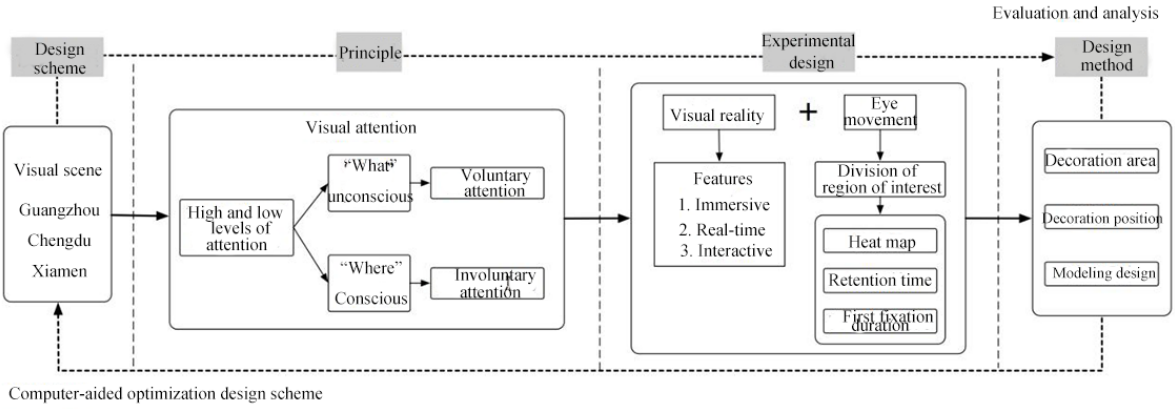

Figure 1: Research ideas.

Xiamen standard subway Chengdu theme subway Guangzhou theme subway

Figure 2: Experimental samples.

principle of visual attention. Based on it, design strategies for subway space were summarized.

The technology combing virtual reality with eye movement which was independently developed by Shanghai Qingtech Co., Ltd., China. An eye tracking module was inserted into HTC vive to track and record the real-time eye movement data in the virtual visual scene. Research ideas are shown in Figure 1.

4.1 Survey of design cases and selection of samples

Sixty-nine design cases of theme subway in 24 cities in China were collected, and two of them was selected as the representative experimental samples. Panda theme subway on Line 3 in Chengdu and cartoon theme subway in Guangzhou were selected as comparison samples, and the standard subway on Line 1 in Xiamen was selected as the reference of this study, as shown in Figure 2.

In the panda theme subway on Line 3 in Chengdu, panda which is a regional cultural characteristic of Chengdu was taken as the design element, and the image of panda was integrated into the appearance design of seat, handle and side walls to create three-dimensional models.

The standard subway on Line 1 in Xiamen has no theme, which is the mode of most standard subways in China. Analysis on recombination of design elements. As the design of theme subways involves many factors, pattern area,modeling technique and decoration position were selected as the key elements for comprehensive analysis.

The proportion of pattern area refers to the proportion of the pattern area inside a carriage to the total area, and it has three grades, 10% ~ 30%, 30% ~ 60% and 60% ~ 100%.

Modeling techniques include design of three-dimensional modeling and design of texture. Design of three-dimensional modeling mainly focuses on positions of handles, handrailings and seats, while design of three-dimensional modeling focuses on side walls, end walls and top surface.

Design elements were classified and then recombined. Two design issues were analyzed. The first issue was the comparison of subway facility design in different themes but at the same position, and the second issue was the comparison of visual perception of different spatial interface design in the same theme but at different positions. Based on it, design strategies of hardware facilities and interface which was more in line with the principle of visual attention could be put forward. Details are shown in Figure 3.

4.2 Subjects

In this experiment, there were 30 subjects, aged 18 ~ 35 years. In order to ensure that all the subjects had the same cognitive level, all of them had no virtual reality experience, but had the experience of taking the subway. The uncorrected or corrected visual acuity of the subjects were normal, and neither of them had color blindness. At the beginning of the experiment, the subjects were asked to receive an eye movement calibration test which lasted for 30 ~ 60 s in the scene. The formal test started after the eye movement calibration; they had a visual activity

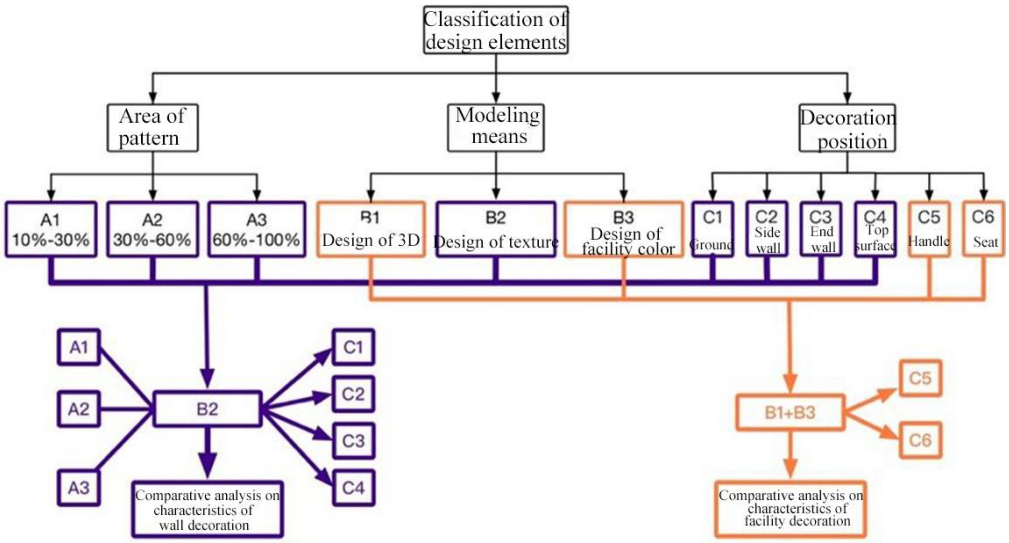

Figure 3: Two design issues corresponding to the recombination of design elements.

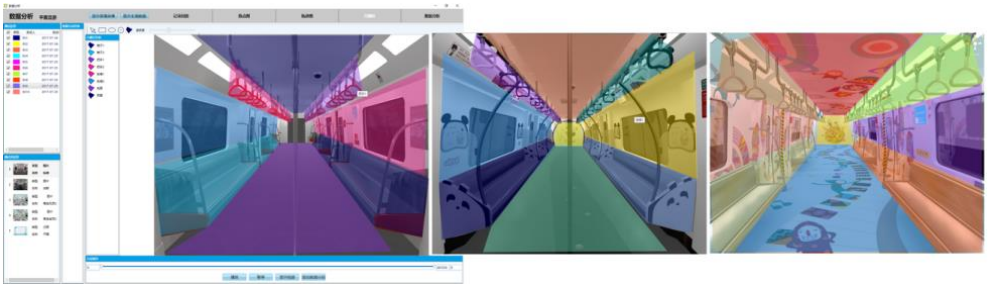

Figure 4: The division of area of interest in three subway carriages.

of random observation in the virtual scene which lasted for 120 s.

4.3 Analysis of experimental results

Firstly, the area of interest inside the subway was divided. As shown in Figure 4, the subway carriage was divided into six regions of interest according to the space region and functional facilities: top surface, side walls, end walls, ground, handles and seats. The first fixation duration and retention time in the six regions of interest were recorded. The mean values and variances of the eye movement data were statistically analyzed using SPSS to evaluate the internal design of the carriage.

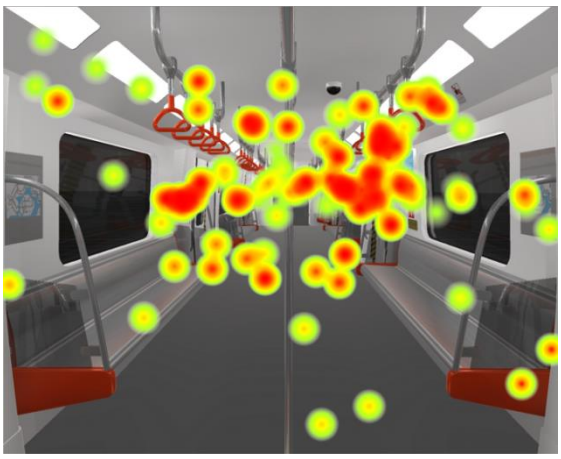

Figure 5: Analysis of the heat map of a standard subway.

4.3.1 The comparison of facility design in the same theme but at different positions

User will unconsciously observe firstly when he enters a [Pritegnite pozornost bralca z odličnim citatom iz dokumenta ali pa izkoristite ta prostor, da poudarite ključno točko. Če želite premakniti to polje z besedilom na katero koli drugo mesto na strani, ga preprosto povlecite.]
carriage for the first time. The impact of different subway facility designs on the attention of users was analyzed. According to the analysis of the heat map of the standard subway, it was found that the seat and handrail facilities of the subway were the concerns of passengers, as shown in Figure 5. Therefore, different designs of positions of handrails and seats in the subway carriage was compared. The fixation condition of users in an unconscious state was analyzed by performing descriptive analysis on the first fixation time of users, as shown in Table 1.

Different design methods for the same location and different themes have different effects on eye movement data. The three-dimensional design of the seats and handles which took panda as the element in the Chengdu theme subway attracted the most interests and attentions from users, as shown in Figure 6. The minimum value was 43.83, and the sensitivity was high in the early recognition process. Next was the standard subway, the

Table 1: The descriptive analysis results of the first fixation in the facility design.

Descriptive statistics of the first fixation time in the facility design					
Facility	**Experiemntal samples**	**Mean value**	**Remark**	**Standard deviation**	**Remark**
Seats	Standard subway	70.27	Smaller mean value means users are more likely to pay attention to the facility.	73.21	Smaller value of standard deviation means smaller difference of experience tendency.
	A subway in Chengdu	43.83		57.13	
	A subway in Guangzhou	82.00		81.76	
Handles	Standard subway	65.49		69.97	
	A subway in Chengdu	51.55		50.79	
	A subway in Guangzhou	68.24		42.83	
Remark: the unit of the first fixation time is second.					

Figure 6: Design of facilities.

handles and seats were red with high saturation degree, which was in sharp contrast with the surrounding environment. Its value was larger than the Chengdu subway (70.27 > 43.83). Therefore, the three-dimensional design was better than the high saturation color design. The handles and seats of the theme subway in Guangzhou were gray and unified with the surrounding environment. Its value was the highest (82.00 > 70.27 > 43.83) and had a large gap with the eye movement data of the other subways. Therefore, model color design which was close to the environmental color had the least attractiveness and the lowest sensitivity to the early recognition reaction.

Through the above analysis, it was concluded that there were two design methods of theme subway facility. The first one was design of color, and the second one was design of three-dimensional modeling. Both had advantages and disadvantages. The design strategies are shown in Table 2.

In China, the Disney theme subway in Hongkong is a combination of three-dimensional modeling and color design, which conveys the theme of Mickey always accompanies with passengers. In the design of windows

Table 2: The design strategy for hardware facilities in theme subway.

	Design method of facility	
	Design of color	Design of three-dimensional modeling
Advantages	High economical efficiency: low construction cost	1. The application of thematic image has strong visual attraction. 2. High identifiability and highly sensitive to the early recognition reaction. The application of personification design and skeuomorph makes facilities more visually hierarchical.
Disadvantages	1. Weak visual attraction 2. Low sensitivity to reaction and weak identifiability 3. Similar design style	1. Complex manufacturing technique (customized design) 2. Higher cost compared to the design of standard subway 3. Individualized design for every theme, lacking of sustainability.
Conclusions for optimizing strategy	Three-dimensional modeling + color design 1. Abstract design of thematic images (serialization design of handle, support rod and connecting rod) 2. Serialization design of handles and seats to strengthen content of theme 3. Pay attention to the complementarity of facility color and surrounding environment in subway carriage.	

Table 3: The sorting of average retention time of different space interface.

The sorting of average retention time of different space interfaces											
	1		2		3		4		5		6	
Guangzhou	Top surface	6.33	End wall	4.80	Ground	4.33	Side wall	3.47	Seat	1.79	Handrail	1.46
Chengdu	Side wall	3.81	Ground	1.87	Seat	1.87	Top surface	1.56	End wall	1.35	Handrail	1.28
Standard	Side wall	2.84	Handrail	1.1.8	Ground	1.11	Top surface	0.91	Seat	0.89	End wall	0.77
Remark: the unit of the retention time is second.												

and handles, the three-dimensional design of "Mickey head" is adopted. The three-piece handle attracts attentions of passengers by contrast colors, red, yellow and black. The arrangement of the seats breaks out the previous end-to-end arrangement. The L-shaped blue corner cloth sofa contrasts vividly with the yellow on the surrounding supports in the whole space. The echoing of color stimulus and theme modeling also leave a deep impression on people, as shown in Figure 7 [xv].

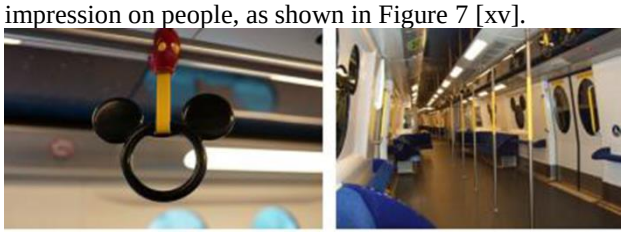

Figure 7: The design of internal facilities of the Disney theme subway.

The space interface of subway carriage can be divided into top surface, ground, side walls and end walls; passengers pay more attentions to these four parts. Therefore, dual requirements of functional technology and the aesthetic level of space need to be satisfied. Taking the theme subway in Guangzhou and Chengdu as examples, the influence of wall design on visual retention and attention of users was discussed to conclude the design features of different locations inside the subway [xvi].

4.3.2 The comparison of facility design in the same theme but at different positions

First of all, variance analysis of retention time of eyes was made. The significance of position * theme Sig=0.027<0.05 indicated a significant difference; it meant that the decoration position was interactive with theme design. Eye retention time of the decoration

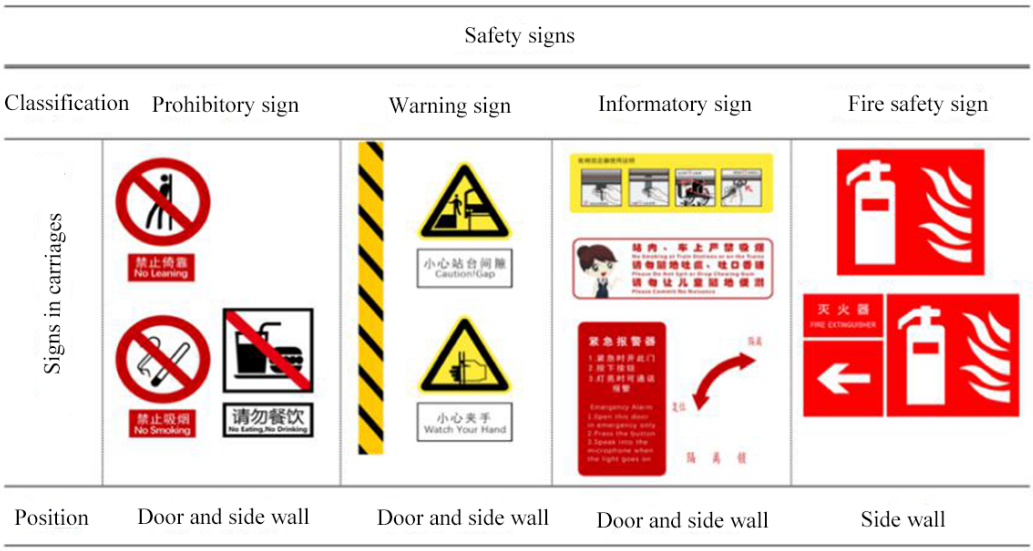

Figure 9: Functional information signs and the distribution positions.

position varied with the theme. Significance Sig=0<0.05 indicated a statistically significant difference in data of different locations. However, the variance analysis of the first fixation time found that significant of position * theme Sig=0.762>0.05 indicated no statistically significant difference, showing that the user was in the unconscious state and the decoration position was non-interactive with the theme design. For further analysis, data were processed by descriptive statistics, and the eye movement data at different locations on the same theme were sorted preferentially, as shown in Table 3.

Through descriptive analysis, it was found that users had different degrees of information processing at different locations after entering the carriage. The comparison of the top three positions suggested there was a commonality although users had different fixation points. In all regions of interest, ground and side walls in all the carriages were observed, which conformed to the behavioral mode of people in subway; they were also the keys in the design.

The side walls of Chengdu theme subway is designed based on panda and labeled with text information, as shown in Figure 8. The first fixation time of the side walls was 60.13 s, indicating that it was paid less attention to compared to the Guangzhou subway. But after a long-time observation, the fixation time of the side walls was 3.81 s; with a high readability, it could attract more attentions and interests.

Therefore, it could be concluded that the side wall is an important position which users will pay attention to for a long time. Situational decorative design was not suitable for side walls because of the region segmentation and functional information, as shown in Figure 9. These signs can provide information services such as instructions, hints and warnings to passengers through visual communication, which plays a key role in the safety of passengers in the subway station. Without affecting the search of functional information, small texture design or three-dimensional modeling design can be used.

Figure 8: Text information on the side walls of the Chengdu subway.

The Guangzhou theme subway focused on texture design, and users paid more attentions to the top surface (6.33 s), the end wall (4.80 s) and the ground (4.33 s) which had complete content. Due to the pattern integrity and sufficient scene presentation of the top surface, users observed it for a long time and paid the most attentions to it. Therefore top surface was the best place to display the situational theme design; while maintaining the spatial integrity, it would not interfere with the search of the functional information inside the carriage. Currently, there are few theme subways with designed top surface, and it is also easily to be ignored by designers. For the design of ground, small area or monotonous color design can be used as it has certain behavioral functions and easy to wear because of the large staff mobility.

In the process of experiment, the visual attention reaction of users was tested by changing the saturation of the side walls of the theme subway in Guangzhou. When the saturation was too high or low, the user's attention was quickly transferred to other areas. Therefore, it was concluded that color saturation was an important factor affecting the visual attention of users. It was suggested that designers use moderate saturation for the overall space of carriage, and the area that needs to be noticed by the user can be used in the contrast of high saturation color. The optimization strategy is shown in Table 4.

Table 4: The summary of optimization strategies for the interface design of theme subway.

Position	Characteristics of positions	Conclusions of optimization strategy
Side walls	1. Region division and many functional information 2. Small designable area 3. An area which is focused on 4. High information readability	Consideration for safety: 1. Design of small-area texture or design of three-dimensional modeling is allowed on the premise of not affect searching of functional messages. 2. Not suitable for large area of situational pattern design 3. Suitable for reading of text messages in theme design 4. Pattern design around guiding messages in the area of side door is not suitable as it will increase time of searching messages.
Top surface	1. Large designable area 2. No region division on the wall surface, with a high integrity 3. Presenting visual height	**Consideration for comfort** 1. Present situational theme design with design of texture 2. Not suitable for layout of text information 3. Passengers may feel reduced visual height and feel depressive because of complex pattern 4. The saturability, relative brightness and hue of patterns has large influence in improving the visual height of space (visual perception stratification).
Ground	1. Large designable area 2. No region division on the wall surface, with a high integrity 3. With a behavioral function 4. Easy to wear	Consideration for function 1. Design of small-area texture or monotonous color design are feasible. 2. Large-area texture design is not suitable as the large passenger flow in the carriage is prone to cause wearing.

5 Conclusion

Several design strategies of color, shape and texture were developed based on virtual reality technology, reference to different theme subway space, eye movement data and subjective evaluation for the design of hardware facilities and interface in theme subway, which can provide a reference for future design. In future research, virtual reality technology in combination with eye movement technology can be used for the study of the spatial availability of the environment to offer users a better experience in the space.

6 Acknowledgement

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