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The Influence of Spatial Cognitive Model Based on Eye Tracking on Wayfinding Behavior in Underground Parking Lots

Dong Lv, Qiang Wei*, Chen Wang, Yanan Liu and Binghai Su
Department of Psychology, Jianghan University, WuHan, HuBei, China

*Corresponding author's e-mail:
weiqiang@jhun.edu.cn

Abstract. Objective In view of the fact that the demand for indoor commercial underground parking lot maps is rising, the effect of underground parking lot map navigation with different spatial cognitive modes on individual wayfinding was studied from the perspective of spatial cognitive modes. Methods Firstly, Unity3D software was used to build the underground parking lot environment, and maps with different types of spatial cognitive modes were used as variables, and single factor analysis was used to record and analyze the number of hesitations of subjects in the process of wayfinding; secondly, eye-movement cognitive data of visual forms were obtained based on eye-tracking experiments; finally, the spatial cognitive modes of users and eye-movement indicators were combined to make recommendations on the design of underground parking lot maps and underground Finally, we suggest the improvement of the underground parking map design and the setting of underground parking related facilities based on the user spatial cognitive patterns and eye-movement indexes. Conclusion The map design affects the navigation effect of users in the process of finding the way in the underground parking lot, and the optimized design method of correlating spatial cognitive patterns and eye-movement tracking indicators is established to provide users with a convenient navigation experience and improve the equipment and facilities related to the underground parking lot for the shopping mall.

Keywords. Mental rotation; 3D simulation; Pathfinding; Number of hesitations; Eye-tracking

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1. Introduction

The font of the whole paper should be Times New Roman.Wayfinding is a search task that requires the understanding of environmental cues and cognitive strategies specific to the task, and can be described as a navigation task to reach a specific destination [1]. It can be described as a navigation task to reach a specific destination. Wayfinding is an intricate cognitive interaction process that involves various types of spatial representations [2] and is influenced by personal factors, environmental elements [3]. Personal factors Personal factors refer to the pathfinder's gender, age, strategy preference, pathfinding anxiety, spatial perception ability, familiarity, cultural differences, and pathfinding experience, etc. [4-6]. The personal strategies used to reach the destination during wayfinding are based on human spatial cognition and information processing [7]. A combination of information collection, processing, spatial knowledge, path direction, and performance calculations has been found to influence individual cognitive and response behaviors on wayfinding in both indoor and outdoor environments [8]. People with high environmental familiarity rely more on extracting information from memory, cognitive memory and previous mental mapping of the environment rather than environmental information, and information retrieval from memory nodes and long-term memory has a strong influence on pathfinding planning and defining routing strategies [9]. Pathfinding in spaces with low familiarity is prone to anxiety, which leads to a decrease in pathfinding efficiency [10]. The pathfinder in a space with low familiarity will improve the environment familiarity through cognitive maps, localization mechanisms, etc., which will improve the pathfinding efficiency [11].The environmental elements refer to the environmental features such as the environment. Environmental elements refer to environmental features such as environmental complexity, information signs, wayfinding indicators, signage design, and wayfinding aids [12]. The environmental elements have been studied mostly. Environmental elements have been studied mostly in indoor or underground spaces. Information signs can provide spatial orientation guidance and thus greatly influence wayfinding effectiveness [13]. The study found that nationality and the pathfinder influence the wayfinding effect. Studies have found a strong relationship between nationality and the wayfinder's understanding of the signage message, so a better understanding of the wayfinder's perspective is needed to effectively communicate the message[14]. The study found a strong relationship between nationality and wayfinder understanding of signage messages.

Underground space has complex paths, stable light, fewer spatial clues, and horizontal spreading compared to ground space, so its pathfinding effect is lower than ground space [15]. The pathfinding effect is lower than that of ground space. The pathfinder tends to move along the edges of the space to reduce the risk of getting lost when searching in underground space [16]. This reduces the risk of getting lost. Some scholars have explored the social cognition, emotional attitude and experience of wayfinding in underground space from the perspective of psychology [17]. Some scholars have explored the social cognition, emotional attitude and experience of wayfinding in underground spaces from a psychological perspective. The sense of orientation in underground spaces is low, which affects the comfort and security of wayfinders [18]. The environment of underground space is more obscured. The more obscured environment in underground space makes it difficult for wayfinders to build cognitive maps through path integration, and fewer spatial cues make individuals unable to provide scene recognition for spatial orientation [19]. Some scholars have also studied the establishment of the sense of direction and the design of directional guidance in underground space from the perspective of architectural design, and proposed design strategies [20]. Some scholars have also studied the establishment of directional sense and directional guidance design in underground space from the perspective of architectural design and proposed design strategies. The spatial cognition, emotional atmosphere and signage system design of underground commercial street have an important impact on wayfinding behavior [21]. The design of spatial perception, emotional atmosphere and signage system in underground shopping streets has an important impact on wayfinding behavior. In addition, the public is not familiar with the horizontal and vertical navigation functions in the map navigation and the vertical navigation function is not perfect, which makes it more difficult to find the way in the underground space [22]. Therefore, it is important to improve the service design of map navigation. Therefore, to improve the service design of map navigation and enhance the effectiveness of map navigation as a spatial cognitive tool in underground parking is an important research direction for indoor commercial underground parking lots. Therefore, this study takes the map design and signage design of underground parking lot as the starting point to conduct research [23]. Therefore, this study takes map design and signage design of underground parking lots as the starting point.

Wayfinding behavior is related to spatial perception ability, mental rotation ability, short-term memory and abstract reasoning ability, and mental rotation ability is more influential in virtual scenarios [24]. The pathfinder perceives the distance between himself and the target through self-motion perception, and then adjusts his direction and position according to the mental map.[25] . Mental rotation ability and abstract reasoning ability have a greater impact on pathfinding decisions in virtual environments and vary with the characteristics of the spatial environment [26]. The mental rotation ability and abstract reasoning ability in virtual environments have a greater impact on wayfinding decisions and vary with the spatial environment characteristics. Some scholars have studied the directional cognitive process of users' turns in electronic navigation maps and found that maps with different spatial cognitive modes play an important role in users' navigation process [27]. Therefore, in this study, the mental rotation and target search of the subjects in wayfinding were considered, and the maps were processed in the design of the maps, and different navigation maps were set up to study the maps with different spatial cognitive modes as variables.

The cognitive performance of a pathfinder in an unfamiliar environment can be reflected by eye movements, so the use of eye-tracking technology can effectively restore the cognitive process of a pathfinder and improve the existing cognitive models, or even create new cognitive models for describing and predicting human behavior [28]. The use of eye-tracking technology is an important tool for the development of new cognitive models. Eye tracking technology is an important psychological and marketing technology, which is widely used in the fields of education, product design, traffic safety, advertising and marketing, medical and health care, etc. [29 - 34] Eye tracking is an important psychological and marketing technology used in education and teaching, product design, traffic safety, advertising and marketing, medical and health care. Eye tracking technology has been richly researched in pathfinding and spatial cognitive mechanisms. It is often used to investigate the most effective landmarks in visual wayfinding aids [35]. Some scholars have used eye-tracking technology to explore the function of wayfinding signage in university libraries, demonstrating that information signage has the best visual navigation capabilities and is the most popular among route strategy users [36]. In indoor complex healthcare environments, identification signs, informational signs and architectural features are the most important wayfinding elements that attract the eyes [37]. In a radial shopping environment, customers obtain effective wayfinding information in the form of orientation signs and spatial structure cues as the main information perception process [38]. Some scholars have also explored the optimal signage system. Some scholars have also explored the interaction between the optimal location of signage systems and viewing characteristics, and found that the viewing points are usually between 100 cm and 150 cm (vertical height) in corridors and intersections, and that the height of signs does not correspond to the viewing points of most people, recommending that the location of signs be changed according to the type of connection point [39]. It is recommended to change the location of the sign depending on the type of connection point. Gender use of signs found that females relied more on landmarks for navigation and exhibited sustained landmark gaze, while males showed a decrease over time [40]. Eye tracking techniques can also be used to detect spatial familiarity in wayfinders, with pupil diameter, gaze dispersion, sweep duration, gaze count and duration on the map being important features for detecting familiarity [41].

This study focuses on exploring the influence of spatial cognitive patterns on wayfinding behavior in underground parking lots. Using a combination of behavioral experiments and eye-tracking technology, Unity3D software was used to build a virtual underground parking lot spatial environment, maps with different types of spatial cognitive patterns were used as variables, single

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factor analysis was used to record and analyze the number of hesitations of subjects during wayfinding, and then eye-movement cognitive data of visual forms were obtained based on eye-tracking experiments, through gaze duration, gaze times, hot spot maps and other eye-movement data [42]. The results of the eye-tracking experiment were used to determine the effects of mental rotation and target search on the attention and processing of information in the process of wayfinding in underground parking lots. Finally, combining the user's spatial cognitive patterns and eye-movement indexes, we summarize the effective ways to improve the wayfinding efficiency in underground parking lots, and suggest improvements to the design of underground parking lot maps and the setting of underground parking lot related facilities.

2. Methods

2.1. Behavioral experiments

2.1.1. Participants

The subjects were 118 undergraduate students, and invalid data were excluded from the analysis of results, resulting in a final valid sample size of 81 (18 males and 63 females) with a mean age of 19 ± 2 years. All subjects had normal or corrected visual acuity and were right-handed. Subjects were randomly divided into two groups, each receiving different levels of treatment, with 27 subjects participating in the experiment without map condition and 54 subjects participating in the experiment with map condition.

2.1.2 Stimuli

(1) The computer presents a 3D simulated underground parking model created by Unity3D software.
(2) A video is recorded from the first viewpoint of the driver walking from the entrance of the underground parking lot to the set parking space.
(3) The subject's pathfinding process was recorded and analyzed using Camtasia Studio 8 video recording software, mainly recording the user's
(4) Use PowerPoint office software to create two kinds of underground parking lot map materials with a size of 1280×720(as shown in Figure 1).
(5)Mental rotation ability test, which functions as a distracting stimulus during the experiment.

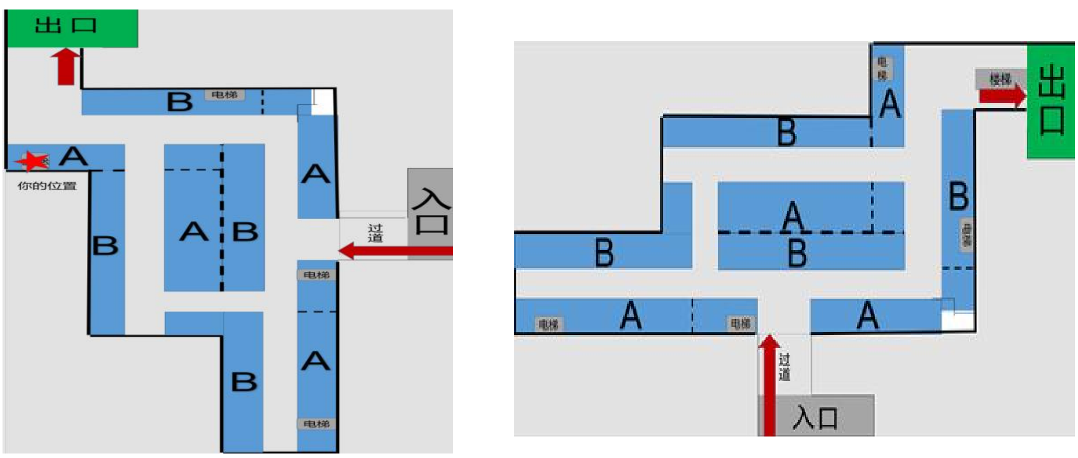

Figure 1. Mentally rotated map and non-mentally rotated map.

2.1.3. Procedures

The independent variable of this experiment was the presentation of the map, and the dependent

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variable was the number of hesitations during the subjects' car search. A one-way between-subjects experimental design was used.

Phase 1: Video learning and map familiarization phase

(1) The subject was first presented with a pre-recorded video recording of the subject walking from the entrance of an underground parking lot to his or her parking space with his or her own vision. Before the presentation, the subject narrated the following instruction: "This experiment is a wayfinding experiment, first we will show you a video in which we record 'you' walking from the entrance of this underground parking lot to 'your ' parking space, during which you need to remember two things: first, you need to remember what your car looks like; second, you need to pay attention to your surroundings, because your task is to find that car". Next, a video is played to the subject, and the character in the video needs to be reminded that the car in front of the subject is the car that the subject needs to find when he or she walks to the parking space, and after the video is played, the subject needs to be reminded that the starting point of the pathfinding is not the same as the place at the end of the video.

(2) Subjects were then asked to complete mental rotation ability test questions, the main function of which was to allow the subjects to forget the previously watched videos, with no time limit on doing the questions.

(3) Next, the subjects were presented with a map of the underground parking lot, which was the familiarization stage. The subjects were randomly divided into two groups. The first group was given two different types of maps at random, and the second group was not given a map of the underground parking lot, in which the first group was given 30s to familiarize with the map.

Phase 2: Pathfinding phase

The subject was asked to start the pathfinding process, and before the pathfinding, the subject announced the following instruction: "Your next task is to find the car that appeared in the video, and you need to follow the main road in the process of finding the car, without any time limit, until you find the car". The subject can manipulate the experiment by using the arrow keys, and the whole process of the experiment will be recorded on video for data analysis.

2.2. Eye tracking experiments

In order to further analyze the subjects' gaze behavior towards objects in the underground environment during wayfinding, this experiment continued to set up a follow-up eye-tracking experiment. This study can help us to modify and improve our work in actual underground parking lots.

2.2.1. Participants

The Tobii Pro Glass 2 oculomotor was used to record the subject's gaze behavior towards the surroundings during pathfinding, with a sampling rate of 50 Hz, enabling a coherent calibration process. The rest of the experimental material was the same as in the formal experiment. The total number of subjects in the follow-up experiment was 18 subjects, 5 males and 13 females, of which the number of valid subjects was 9.

2.2.2. Procedure

(1) The subjects were instructed to put on the eye-tracking device, perform the calibration process, and then enter the experiment. The subject was first presented with a pre-recorded video, and the experimental requirements and instructions were the same as those of the formal experiment.

(2) Unlike the formal experiment, subjects did not need to complete the test questions of mental rotation ability and went directly to the map study, which also randomly divided subjects into two groups and provided maps with different spatial cognitive patterns.

(3) Finally, the subjects were asked to look for the car in the video, and the operation and instructional phrases were the same as those in the formal experiment. Subjects were required to wear an eye-tracking device at all times for the entire experiment.

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Figure 2. Subjects wearing an eye-tracking device for the experiment.

3. Results

3.1. Behavioral results

A one-way ANOVA revealed that the main effect of the map with underground parking was significant, $F(2,78)=19.224$, $p<0.01$. The main effect of the map with mental rotation of underground parking was not significant, $F(1,78)=0.197$,$p>0.05$. The main effect of the map without underground parking was significant, F(1,78)=38.252,p& lt;0.01. According to Table 1, there was a significant difference in the number of subjects' wayfinding hesitations in both the provided map condition and the no map condition treatment, which is consistent with the hypothesis of this experiment, indicating the significant effect of the guidance role of maps in the subjects' wayfinding process. Map navigation can effectively help wayfinders to cognitively remember and construct mental image maps[43] The map navigation can improve the efficiency of wayfinding in underground parking lots. In the actual underground parking lot, the number of maps about the underground parking lot can be appropriately increased to help the subjects find their way.

Table 1. Data on the number of hesitations in subjects' wayfinding when presenting maps with different spatial cognitive patterns (M±SD).

Map Type	Number of hesitations	P
The map without mental rotation	3.11±0.371	0.000
Mentally rotated map	3.00±0.256	0.858
No map	6.37±0.607	0.000

3.2. Eye tracking experimental results

The experimental data recorded by Tobii eye-tracking device with the synchronization software Ergolab were subjected to outlier rejection, and the data were entered into SPSS for descriptive statistical analysis.

3*.2.1. Number and duration data results for at for each sign at the parking space*

Using the location of the marker point as the independent variable and the AOI gaze point and gaze point duration as the dependent variables, the independent variables were tested on the dependent variables.

The results of the tests are shown in Table 2. The descriptive statistical analysis of the number of viewpoints and duration of each sign at the parking space showed that the number of viewpoints of the sign above the parking space (M=4.06, SD=1.208) was significantly more than that of the wall sign

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(M=3.33, SD=0.882) and the aisle sign (M=4.00, SD=0.707) during the video learning. Aisle signs had significantly more gaze point duration (M=1.60, SD=0.258) than wall signs (M=1.25, SD=0.105) and signs above parking spaces (M=1.08, SD=0.292), and wall signs had more gaze point duration than signs above parking spaces (see Table 2, Figure 3).

Table 2. Number of fixation points and duration of each sign at the parking space during video learning (M±SD).

Marker Points	Number of attention points	Focus point duration
Wall Signs	3.33±0.882	1.25±0.105
Sign above the parking space	4.60±1.208	1.08±0.292
Passage marking	4.00±0.707	1.60±0.258

During the car search, the number of viewpoints for the above parking space sign (M=3.50, SD=1.323) was significantly more than the wall sign (M=2.50, SD=0.500) and the aisle sign (M=2.33, SD=0.333), and the number of viewpoints for the wall sign aisle sign was significantly more than the aisle sign. The duration of viewpoints for channel signs (M=1.06, SD=0.314) was significantly more than that for wall signs (M=0.96, SD=0.160) and signs above parking spaces (M=0.77, SD=0.274), and the duration of viewpoints for wall signs was more than that for signs above parking spaces (see Table 3, Figure 3).

Table 3. Eye movement data of the number of fixation points and duration of each sign at the parking space when searching for a car (M±SD).

Marker Points	Number of attention points	Focus point duration
Wall Signs	2.50±0.500	0.96±0.160
Sign above the parking space	3.50±1.323	0.77±0.274
Passage marking	2.33±0.333	1.06±0.314

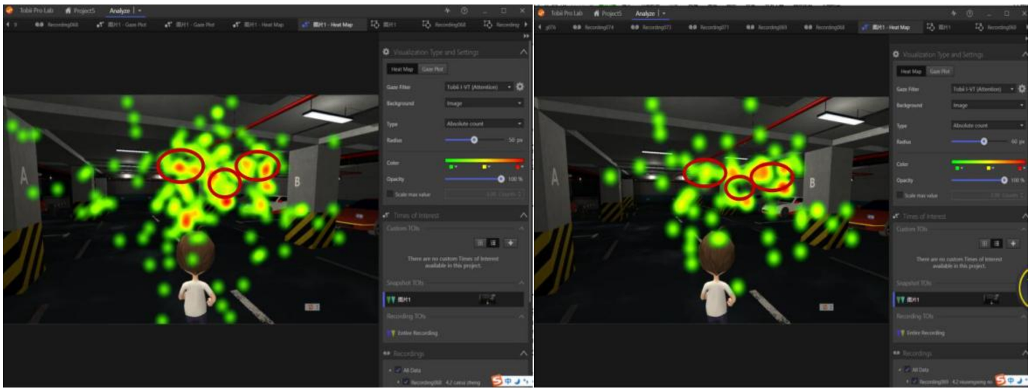

Figure 3. Subjects' eye movement hotspots at the parking space during video learning and searching.

The analysis of the results (see Tables 2 and 3 and Figure 3) shows that the subjects looked more and longer at the signs above the car and in the center of the passage, both when they were looking for directions and when they were remembering the parking space. Signs help users to follow directions

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and lead people directly forward, while directional signs force users to remember this information and confirm the displayed destination.[3] .

3.2.2. Results of data on the number and duration of subjects' gaze points at each important location during the map familiarization phase

The main analysis of the subjects' gaze at the three locations of the entrance (i.e., the video learning is the entrance to the parking lot in the video), the starting point (i.e., at the red star symbol in the map), and the ending point (i.e., at the parking space) during the map familiarization. Using different types of maps as independent variables and AOI gaze points and gaze point duration as dependent variables, the data on the number of gaze points and duration of subjects' gaze points at important locations under different types of maps showed that subjects had significantly more gaze points at the departure point (M=7.50, SD=0.500) than at the entrance (M=5.50, SD=0.500) and the end point (M=2.00) in the non-mentally rotated map condition. (M=2.00), and the number of gaze points at the entrance was significantly greater than that at the end. Subjects had significantly more gaze point durations at the departure point (M=2.67, SD=2.410) than at the entrance (M=0.86, SD=0.360) and the end point (M=0.56), and significantly more gaze point durations at the entrance than at the end point (see Table 4, Figure 4).

Table 4. Eye movement data of the number of fixation points and duration of each important position of the subjects when they were not familiar with the mental rotation map (M±SD)

Marker Points	Number of attention points	Focus point duration
Entrance	5.50±0.500	0.86±0.360
Starting Point	7.50±5.500	2.67±2.410
Endpoint	2.00	0.56

In the after mental rotation map condition, subjects had significantly more gaze points at the entrance (M=3.00, SD=1.000) than at the departure (M=2.50, SD=0.500) and end points (M=1.00), and significantly more gaze points at the entrance than at the end points. Trials had significantly more gaze point durations at the departure point (M=0.88, SD=0.420) than at the entrance (M=0.84, SD=0.320) and at the end point (M=0.12), and significantly more gaze point durations at the entrance than at the end point (see Table 6, Figure 4).

Table 5. Number of fixation points and duration of eye movement data of subjects at each important position when they are familiar with the mental rotation map *(M±SD).*

Marker Points	Number of attention points	Focus point duration
Entrance	3.00±1.000	0.84±0.320
Starting Point	2.50±0.500	0.88±0.420
Endpoint	1.00	0.12

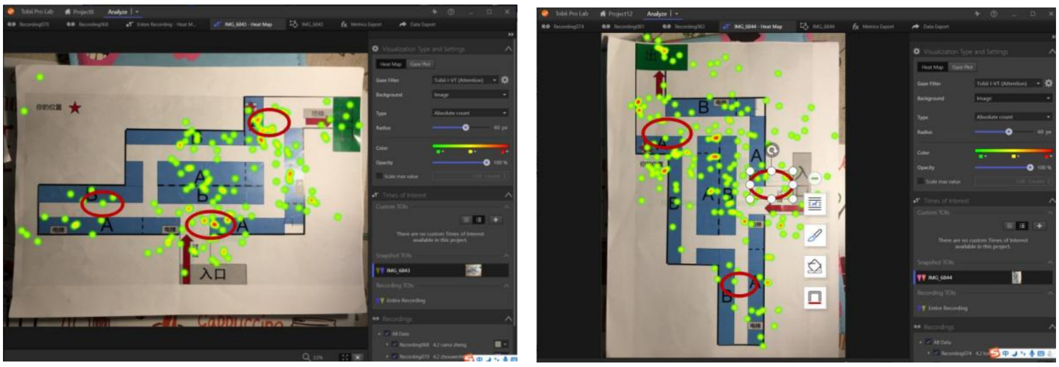

Figure 4. Eye movement heat map of subjects familiar with the map under map processing of different spatial cognitive modes.

It can be concluded that when familiarizing with the map, the subjects were more concerned with the entrance and their current location, regardless of the angle of the map. Therefore, when designing a wayfinding navigation map, the content selection should be as concise as possible, highlighting the entrance and the location of the wayfinder, so as to reduce the memory burden of the wayfinder and improve the efficiency of the wayfinding [24]. The map should be as simple as possible, highlighting the entrance and the location of the pathfinder, thus reducing the memory burden of the pathfinder and improving the efficiency of the pathfinder.

4. Conclusion

In this paper, we investigate the effect of map navigation in underground parking lots with different spatial cognitive modes on guiding users in wayfinding. The number of hesitations in wayfinding was significantly lower when subjects were provided with maps than when they were not. It can be concluded from that the effect of the map in guiding the subjects in the process of wayfinding was significant . However, the present study also showed that there was no significant difference between the maps that were mentally rotated and those that were not, which is somewhat different from previous studies[2] This may be due to the fact that this experiment used paper maps, which cannot be adjusted in real time according to the user's orientation. In addition, the results suggest that the number of maps can be increased at the entrances and exits of the actual underground parking lots, at the elevator entrances, and next to each prominent area sign to help people find their way faster. The analysis of the eye-movement data shows that: (1) people pay more attention to the signs above the parking spaces and the signs above the passageways when remembering the parking spaces and during the car search process, so the maps or signs can be set with a focus on the space above the parking spaces and above the passageways; (2) regardless of the angle of the maps, the subjects pay more attention to the entrance and their current location in the maps, so when Therefore, the design of the actual underground parking map should highlight the entrance and the user's current location, and the content selection should be as concise as possible to reduce the memory burden of the wayfinder, so as to help the wayfinder to find the car more quickly and improve the efficiency of the wayfinding. In this study, there are still some inadequacies to be corrected, such as systematic problems in the production of 3D models, which affect the subjects' wayfinding experience; in the production of maps, more accurate map design is not achieved. In further research, more attention can be paid to the above problems, and the role of the map in the navigation process of the subjects' wayfinding in underground parking lots with more complex internal structures can be further explored for more effective application in real life.

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