Way-Finding Strategies in Underground Space

Zhou Tianfu, Zhang Shanshan, and Bai Xiaopeng

Abstract—**This research identified the preferred way-finding strategy in underground space, and investigated the influence of environmental and personal factors on strategy choice. In overall, results shown that the direction strategy was preferred by navigators over other strategies. For the effects of environmental factors, the visual access was regarded as the most valuable factor in supporting way-finding. Moreover, we found that those navigators who relying on visual access had more possibility to employ direction strategy. For the effects of individual factors, it has been found that the people with keen direction sense tend to employ direction strategies. In addition, males were more likely to use central-point strategy comparing with females. Hopefully, these findings may provide some implications of the way-finding behavior and spatial knowledge learning pattern in underground space.**

Index Terms—**Wayfinding strategy, underground space, environment characteristic, individual difference.**

I. Introduction

Way-finding is the process of moving through space, with the aim of reaching a spatial destination in less time and errors [1], [2]. Investigating the way-finding strategies in underground space is particular imperative for urban citizens. It is because underground space users are more likely to feel anxiety and disoriented without daylight and sight from outside [3], [4]. Though, several studies have investigated the way-finding strategies in complex environment, most of these researches are conducted in above-ground buildings. Whether the research conducted in underground space could maintain the same result is still unclear.

A. Way-Finding Strategy

People tend to rely on different way-finding strategies to reach their destination when there are inadequate spatial information. Researchers indicated there are three basic way-finding strategies, namely, central point strategy, direction strategy and floor strategy [5]. The central point strategy makes use of the dominating parts of certain environment (such as the main hallway or entry hall of building) to arrive at the destination. The direction strategy focus on moving towards horizontal position of destination in regardless of floor level difference [6]. The floor strategy is characterized by moving to the correct floor, before heading towards the goal. In previous studies, the experiment conducted in multi-level buildings demonstrated that the floor strategy is preferred by way-finders and is related with better way-finding performance [7]. However, it seems that the preference of way-finding strategies is highly associated with environment features [8]. There is still limited research focusing on the way-finding behavior in underground space. In this case, we hope this study could shed some light on this issue.

B. Environmental Factors

In the early studies, room number and signage were regarded as the only environmental features that may determine way-finding condition, the effects of spatial design have been underestimated [9]. It is until the 1970, researcher proposed that the decision points of route system could influence way-finding in complex buildings [10]. After that, the decision points' density is typically defined as a measurement of spatial complexity [11]. Furthermore, researches identified four environmental features that could affect way-finding, which are: visual accessibility, spatial difference, complexity of layout and plan configuration [5] [12], [13]. Nonetheless, the findings concerning the effects of environmental factors are inconsistent. For example. some researchers ranked the spatial difference as the major obstacle when visitors navigating in unfamiliar space [14]. In contrast, there are also studies proven that spatial layout complexity is a more important determinant of way-finding strategy comparing with other environmental features [15] [16]. These inconsistencies indicate that the role of each environmental features still need to be explored further.

C. Personal Factors

It has been known that many personal factors could exert influence on way-finding strategies. Plenty of previous studies investigating on this topic, with suggestions that the variables of age [16], [17], spatial familiarity [7], sense of direction [18], spatial anxiety [19] and gender [20] are five personal factors that contribute to way-finding strategies. Even though the impacts of individual variables on way-finding has been agreed by scholars, there are still some controversies over certain issue. Take the gender differences for instance, Lawton reported that women and men tend to use different strategies to find their ways [21], which has been approved by many later researches [22], [23]. However, some studies suggested that males and females use similar way-finding strategies [7], [18], [24]. Based on this condition, further research need to be done to test the effects of personal factors on way-finding strategies in underground space.

D. Research Questions

Based on the literature review, we could conclude that the mechanism of way-finding strategies have been analyzed on the setting of ground space. However, limited studies focus on the seemingly simple, but concurrently complex underground space. How do way-finders behave in underground space? The current study try to extend the research to a different environment lacking daylight, natural elements and outside views. The primary aim of this paper was to explore which way-finding strategies do navigators

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prefer in underground space? Beside that, we wish to clarify the role of environmental factors in underground way-finding process. Furthermore, the correlations between navigators' personal factors and way-finding strategies was examined.

II. Method

A. Participants

Participants were consisted of 52 males and 57 females, who came from universities and institutes in Harbin, China. Their age ranged from 19 to 27 with an average age of 22.4. All of the participants were not familiar with the environment before the survey.

B. Procedure

Generally, the participants' task was to reach the appointed destination on the ground from the starting point in the underground. The experiment was conducted in Hong-Bo Central park, which is an underground commercial space built in 2014. When the survey began, participants were taken to the starting position in the first underground floor. Then experimenter shown participants the photos of destination and told them to find their way to the destination. It need to be mentioned that both the ground and underground part of destination was shown to participants in case of the photo difference bias navigators' strategy choices. Beside that, all participants were the given same instruction in this beginning, because previous study indicated instruction variety could make way-finding process different [7].

Each participant was followed by a experimenter. During the process of way-finding, participants were encouraged to tell the experimenters how they evaluating the routes and anything came to their mind, but they were not allowed to asked for assistance. The experimenters navigating with them would record participants' comments as well as their moving trajectories. After participants arrived at the destination point, they were asked to fill in self-reported questionnaire. The survey would last about 40 minutes.

C. Measures

In this study, a combined methodology of behavior observation, interview and self-reported questionnaire survey would be used to collect the data. For the measurement of way-finding strategy, the traditional way-finding strategy scale would not be used in this research, for some items does not make sense in underground settings (for example the item: "Re-orientating through visualize what was outside"). In this survey, the underground way-finding strategies was measured according to the observed trajectories. Specifically, a direction strategy would be named, if participant try to approach the underground part of destination before moving to the ground. A floor strategy would be defined, if participant leaned to leave the underground space before reaching the destination on the ground. A central point strategy would be assigned, if participant kept tracking the remarkable underground space (such as the main corridor). Apart from these, the ambiguous strategies with two or three mixed trajectories would not be take into account.

We also develop a brief questionnaire to test how participants evaluating the role of environmental characteristics during the navigating. Participants were asked to estimate to what extent do they rely on each environmental features (including: plan configuration, layout complexity, visual access and spatial difference) to find the destination. These questions are answered using 7-point bipolar scale ranging from "highly depend on the item" to "never depend on the item". It need to note that the data from self-administered questionnaire might loss some information, because participants may ignore their unconscious cognitive processes [5], [25]. Hence we also conduct a interview with participants to interpret their answers and way-finding behavior to get a comprehensive finding.

To acquire participants' personal characteristics, all participants were asked to complete a self-reported questionnaire after the navigation. In the first part of questionnaire, participants need to write down their gender and age. The second part of questionnaire included two scales. The Santa Barbara Sense of Direction Scale, a test containing 15 questions, was introduced in the survey to measure the participants' direction sense [26]. In addition, Spatial Anxiety Scale was used to rate the participants' spatial anxiety level [21]. Both scales have acceptable reliability and validity [26], [27]. It need to note that this survey only focus on the people who are unfamiliar with the space. Due to the reason that the people who know the space well would perform an compromise strategy, which will confuse the result [5].

III. Result

A. Way-Finding Strategy

To show the participants' strategy preferences, their navigating trajectories were combined and compared. We could get an interesting result: direction strategy seems to be the first choice of way-finders, followed by central point strategy and floor strategy. This result could also be supported by statistics, which shown that 41% of participants tended to choose direction strategy, 30% of participants adopted central point strategy, 22% of participants used floor strategy and 7% of participants employ unambiguous strategies.

Besides that, experimenters also found some interesting way-finding behaviors in underground space. Firstly, some navigators preferred to walk via underground street. Them stated that they feel easy and safe in this way, because underground space could prevent them from busy traffic and bad weather. Secondly, detour and hesitation were witnessed occasionally during the navigating process. Participants explain their performance as their became unsure about route choice in lack of reference point from outside.

B. Effects of Environmental Factors

In this section, we tried to identify how do participants evaluate the effects of environmental factors on underground way-finding. Then, the association between various environmental factors and way-finding strategy choices was revealed. The data was analyzed by using SPSS 20.0

program.

TABLE I: DESCRIPTIVE STATISTICS FOR ENVIRONMENTAL FACTORS

Environmental factors (N=109)	Mean Value	SD
Spatial differentiation	3.7	1.4
Visual access	5.4	1.8
Plan configuration	3.8	2.1
Layout complexity	3.1	1.6

Table I shown the result of descriptive statistics. It could be found that participants gave a high mean value of 5.4 to the factor of visual access, which indicated people highly rely on visual access in way-finding. The factors of Spatial differentiation (Mean=3.7) and plan configuration (Mean=3.8) seem to play similar important role in way-finding. However, the standard deviation (2.1) of plan configuration shown the participants' views on this factor are various. The factor of layout complexity only got a mean value of 3.1, which could be interpreted as few people would depend on plan configuration to navigate in underground space.

TABLE II: LOGISTIC REGRESSIONS OF STRATEGY PREFERENCE ACCORDING TO ENVIRONMENTAL FACTORS

		Model 2	Model 2
		Odds Ratios	Odds Ratios
Age		No	Yes
Gender		No	Yes
Central-point strategy [a]	Spatial differentiation	1.38*	1.21
	Visual access	2.11*	1.52
	Plan configuration	1.28*	0.93
	Layout complexity	0.73	0.76
Direction strategy [a]	Spatial differentiation	1.71*	1.39
	Visual access	2.52*	1.74
	Plan configuration	0.85*	1.14
	Layout complexity	1.16	1.08

[a] Relative to Floor Strategy
*Significance at 5%

Beside that, logistic regression was used to explore the correlation between participants' way-finding strategy and their perceived environmental characteristics. To begin with, in Model 1, the result implied that people who relying on visual access (OR=2.52) and spatial differentiation (OR=1.71) were more likely to choose direction strategies comparing with floor strategies. Secondly, if participants rely on plan configuration in way-finding, the possibility of choosing direction strategy decreased (OR=0.85) and the possibility of choosing central-point strategy increased (OR=1.28). Thirdly, there is no significant association (Sig ＞0.05) between layout complexity and strategy choices. In Model 2, when adding some personal variables (age and gender) to the regression, the association between environmental characteristics and direction strategy became non-significant and all the odds ratios became closer to 1.0. It suggested that the composition of individual factors might confound the result.

C. Effects of Personal Factors

Table Ⅲ present the result of logistic regression indicating the correlation between personal factors and strategy choices. In overall, only gender difference and sense of direction are significantly associated with participants' way-finding choices. For the gender difference, result shown that male (OR=1.43) were more likely to choose central-point strategies comparing with female. However, female tend to prefer floor strategy in underground way-finding tasks, though the association is only slightly significant (Sig=0.10).

TABLE III: LOGISTIC REGRESSIONS OF STRATEGY PREFERENCE ACCORDING TO PERSONAL FACTORS

		Odds Ratios	Significance
Central-point strategy [a]	Male	1.43	0.04
	Age	0.73	0.24
	Sense of direction	0.84	0.02
	Spatial anxiety	1.12	0.14
Direction strategy [a]	Male	0.87	0.10
	Age	2.91	0.31
	Sense of direction	2.01	0.01
	Spatial anxiety	0.41	0.36

[a] Relative to Floor Strategy

In addition, the sense of direction are positive correlated with the possibility of using direction strategies (OR=2.01). In contrast, the sense of direction are negative correlated with the possibility of using central-point strategies (OR=0.84). There is a marginally significant association (OR=1.12 Sig=0.14) between spatial anxiety and central point strategy, implying that the people prefer to choose central point strategy when their feel spatial anxiety. Contrary to expectation, no significant association was found between age (Sig=0.24, Sig=0.31) and strategy choices, which may due to the data were only collected among young people (average age is 22.4).

IV. DISCUSSION

A. Way-Finding Strategy in Underground Space

The research indicates that way-finders are more likely to employ direction strategy comparing with floor strategy or central point strategy in underground space. This result is inconsistent with the findings from previous studies conducted in above-ground buildings. It could be explained by the principle of spatial information processing when navigators try to approach unfamiliar destinations. It has been confirmed that people prefer to choose the route with more direction information to acquire and less information to store in memory [7], [25].

Based on this theory, in multi-level buildings, navigators prefer to use floor strategies because it reduce the amount of spatial information needed to keep in memory. Floor strategy change the task from three-dimension to two-dimension by moving to the correct floor at first [7]. It need to mention that the preference on floor strategy is based on the premise that each floor containing similar amount of spatial information. However, in underground space, more instructions could be acquired in underground than on the ground. Thus direction strategy seems to be an attractive choice for way-finders in underground. In addition, the preference of direction strategy could be explained by the protective effects of underground space, which has been revealed in previous study [28].

B. Effects of Environmental Factors

In the study, visual access is evaluated as the most important environmental factors in way-finding process. This result is inconsistent with the studies conducted in multi-floor buildings, which regarded the plan configuration as the most important environmental factor[12], [14], [15]. The different environment characteristics may lead to different research result. in multi-level buildings with windows, visitors could understand the plan configuration easily as they could view exterior sights [7]. However, in understand space, navigators could not take advantage of external perspective. Thus, way-finders could hardly rely on plan configuration in underground space. In contrast, high-level visual access provides navigators spatial information directly, which is necessary in a complex environment such as underground space [29].

The current study also found that the people who rely on the visual access of underground environment are more likely to employ direction strategies. It is possible that those people who rely on visual access in way-finding tend to build spatial knowledge based on route information. We may propose that the type of spatial knowledge could affect the choice of way-finding strategy. Clearly, the potential explanation need to be proved in the further investigation.

C. Effects of Personal Factors

The paper revealed the correlation between gender difference and underground way-finding strategy choice. Result shown that men prefer to use central-point strategies comparing with women, which could be supported by many early studies [22], [23]. Though there are also some studies indicated that the association between gender difference and strategy preference is weak [7], [18], [24]. Researchers tried to support their points by using the evidences from experience [30] or biology [31], but there is still no conclusion on the controversy issue. It is possible that the different sample context varies the results, as these researches based on various environment (e.g. multi-floor building, outdoor space or virtual reality). More work need to be done to clarified the effects of gender difference on way-finding behavior.

With respect to the sense of direction, result shown that those participants with better spatial sense preferred to employ direction strategies. Some previous studies shown similar result [18], [27]. However, there are also studies presented opposite result. For example, Kato and Takeuchi found the people with better direction sense tend to use more than one strategy [32]. Some researchers believed there is no correlation between sense of direction and strategies preferences [5]. The argument could be explained by the reason that the individuals with good sense of direction are more likely to change their strategies dynamically according to the surrounding environment [18]. It has been reported participants with good spatial sense would swap easily to "landmark strategy" if there are adequate landmarks in the environment [7]. Therefore, it is not hard to believe that the participants with good direction sense would use direction strategies as there are more spatial information underground.

V. Conclusion

The study explored navigators' preferred way-finding strategies in underground space. The experimental and statistical results shown that navigators were more likely to choose direction strategy. Moreover, the effects of environmental factors and their association with way-finding strategies were also analyzed. It has been noted that the visual access was rated as the most important underground environmental factor in supporting way-finding. Beside that, the paper also indicated that those navigators relying on visual access had more possibility to use direction strategy. Last but not least, the association between some individual features and way-finding strategy choices were also identified. It has been shown that men were more likely to employ central-point strategy. The people with better direction sense are were more likely to use direction strategies.

These findings could be employed as a complement of previous studies, as limited researches focused on the way-finding behavior underground space. Obviously, more work is needed to explore the way-finding process in underground. Firstly, though the preferred way-finding strategy was identified, whether this result could be generalized to more complex space is unclear. Secondly, we also need to explore how do various environmental factors change participants' strategy choices. Thirdly, it is necessary to re-examine the effects of some personal factors on way-finding behavior.

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