User Experience and Map Design for Wayfinding in a Virtual Environment

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Abstract. Virtual environment (VE) has been developed rapidly in recent years. The level of complexity regarding the user interface in VEs has also increased. Users' performance in VEs can be affected by the field of vision, screen size, operation mode, individual difference, and other factors. While little research has been conducted on the effects of user experience and map design on wayfinding in VEs. The experiment is 2 × 2 between-subject design. Participants needed to complete three wayfinding tasks and fill out questionnaires regarding satisfaction, preference, and System Usability Scale (SUS). Forty participants were invited using convenient sampling method. The results are as follows: (1) In terms of the map design, participants performed significantly better by using the semi-transparent map than the opaque map in a difficult task. (2) In terms of the user experience, the results generated from the SUS questionnaire showed that experienced users had a significantly better subjective evaluation of interface usability than inexperienced users.

Keywords: Virtual environment · Wayfinding · Map design · User experience

1 Introduction

Virtual environment (VE) has been developed rapidly in recent years. The level of complexity regarding the user interface in VEs has also increased. Studies on wayfinding in VEs involve cognitive science, human factors, computer science and other fields. Machines are connected with humans by cognitive science, which inquire about the differences between humans and man-made objects in settling problems and the complicated inner workings [1]. Human factors are defined as a science field of creating a proper environment with safe and useful equipment for humans [2].

According to Darken and Sibert [3], VEs are classified by three attributes: size, density and activity. All the details of a large VE cannot be seen from a single viewpoint. There is a relatively large number of objects and cues in a dense VE, the objects obscure important cues and the positions of objects are not predictable. The positions and values of the objects with low activity do not change over time in a static environment. In our study, the controlled environment was a large and dense virtual exhibition with low activity. Users were immersed in the VE and allowed to explore the 3D scenes with input controller freely. Information visualization should be clear on wayfinding maps. Making use of transparency to represent layers of information seems to be an intuitive utilization. The frequency of using transparency on a wayfinding map

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is increasing, while studies on wayfinding map design only involved color, view, landmarks, level of detail and so on.

Users' performance in VEs can be affected by the field of vision, screen size, operation mode, individual difference, and other factors. There are two main types of perspective in VEs: the first-person perspective and the third-person perspective. Research conducted by Schuurink and Toet [4] indicated that adopting the third-person perspective can provide wider vision than the first-person perspective, but it also takes more time to find the target. Our study adopted the first-person perspective which is often used in virtual exhibitions, users pay more attention to the details of exhibits rather than the surrounding environment. Expect the environmental features, the interplay between individual abilities and environmental features can affect wayfinding performance [5]. Therefore, user experience should be considered as a prominent personal factor which could help wayfinding in VEs.

The goals of this research study are: (1) To explore the main issues of map design for wayfinding in a VE; (2) To investigate how map design affects wayfinding tasks in a VE; (3) To investigate how user experience affects their wayfinding behavior in a VE.

2 Map Design

Maps, which visualize spatial relationships with graphs, have been widely used to aid navigation in people's lives. On the aspect of carrier, maps are divided into electronic and paper maps. Electronic maps are not limited in size or display resolution. In terms of content, maps can be divided into general maps, thematic maps and pictorial maps. The main geographical features are reflected on general maps to emphasize the accuracy of spatial relationships. A thematic map usually adds an extra layer of concept upon the layer of general map. Instead of locations, the structure of a natural element or a social and economic issue is manifested in a thematic map. Pictorial maps, such as road maps and tourist maps, are not limited by the precise proportion of geographic locations. Pictorial maps could use various forms of expressions to suppress details and highlight the subject, conveying the theme. In direction, maps are divided into north-up and track-up maps. The environment is fixed on a north-up map, the icons representing users moves in the direction of users. Track-up mapstrack the direction of users' gaze and rotate with the users. In this study, the north-up maps are electronic and pictorial.

Map design, a combination of art and science, directly affects users' performance and feelings. Robinson [6] proposed principles of map design: (1) Letters and symbols are legible; (2) The contents of map have visual contrast to be discriminated; (3) The relationship between figure and background is handled well to make the main contents easy to be recognized; (4) The organization of map has hierarchy of features. Darken and Sibert [3] concluded that principles of map design in real world can be applied in VEs.

Basic graphic elements on maps, including point, line, plane and volume, are designed by changing the hue, brightness, saturation, transparency and other factors of the elements, which ensure the main content, headline, legend, illustration, scale and direction indicator are reasonable. The less target background similarity there is, the faster searching will be [7]. Using different degrees of transparency can display varying levels of importance. Opaque figures with clear borders improve the strength of visual stimulation to present important information. On the contrary, figures with a high degree of transparency present less critical information. But at the same time, figures which have light color could display more information to make best use of screen space. Effects of the transparency of maps on wayfinding performance and users' feelings in VEs are still to be confirmed.

3 User Experience

The experience of using smart devices is constantly changing in the face of new devices and functions. Forlizzi and Battarbee [8] clarified users' experience in interactive systems, the authors proposed three types of user-product interactions and three types of experience. Fluent interactions are automatic and practised, cognitive interactions focus on the product at hand and can result in correct knowledge or contrast; expressive interactions help users form relationships with products. The first type of experience is the continuous "self-talk" which occurs during the interactions. The second type of experience with a clearly defined start and end often makes changes in emotion and behavior. Co-experience, the third type of experience creates meaning and emotion through social interaction.

To understand the meaning of wayfinding maps in VEs, visual information is connected with the experience stored in memory, and then the process from perception to cognition is completed. Norman [9] suggested three types of human memories: sensory memory, long-term memory (LTM) and short-term memory (STM). The stimulus gets to the human sensors and is stored in the sensory memory for an extremely brief time. The stimulus is transmitted to the human brain and temporarily held in the STM [10]. Bailey [11] claimed that designers should try to know about the information stored in users' memories, and how to help users perform well through using new stimulus. If new information has a relationship with something in the LTM, it is easy to get into the LTM.

Users who know information technology devices well are more accurate and decisive in wayfinding [12]. Experienced users hold the usage of wayfinding aids in their LTM to help conduct wayfinding tasks in VEs. The operation and function of aids should be consistent with users' experience to meet their expectations.In this study, user experience referred to the usage of maps as wayfinding aids in VEs such as virtual museum, racing game and city navigation.

4 Methods

4.1 Participants

A total of 40 participants (20 men and 20 women) were invited to take part in a wayfinding experiment based on convenient sampling method. Half the participants have experience of using maps as wayfinding aids in VEs and the other half did not have user experience. 7 of the 20 experienced participants (35%) used maps in VEs more than 3 times a week. Participants who used maps in VEs once or twice a week, less than once a month, or one to three times a month were no more than 5 people (25%). Eighty percent of experienced participants have at least half a year of experience. 7 people have more than 3 years of experience (35%). 6 people have 1 to 3 years of experience (30%). People who have half to one year of experience, 1 to 3 months of experience, or 3 to 6 months of experience were less than 3 people (15%).

All of participants were university students aged from 18 to 30 years, 25 undergraduate students and 15 graduate students. 36 people used internet for an average of more than 2 h a day (90%). More than fifty percent of participants used internet for 2 to 6 h a day. Thus problems in basic operation during the experiment can be prevented. All participants finished tasks successfully.

4.2 Materials and Apparatus

A virtual exhibition area was created with 3D software, and the map of the exhibition was created with 2D software. The experiment operation was configured with 3D game engine. This experiment was conducted on an iPad Air 2. The 9.7-in. retina display was set to a resolution of 2048 $\times$ 1536 pixels. All experimental applications were run under the iOS 9.3 operating system.

4.3 Experimental Design

This experiment adopted a 2 (map design) $\times$ 2 (user experience) between-subjects design. According to the independent variables, participants were divided into four groups. There were two types of maps adopted in this study, i.e., an opaque map and a semi-transparent map. Previous studies have found that user experience is an important personal factor that makes a difference in the accuracy of wayfinding. Therefore, the experimental design included experienced users and inexperienced users.

The research hypotheses are as follows: (1) The operational efficiency of the opaque map may be significantly different from that of the semi-transparent map. (2) The subjective evaluation of the opaque map may be significantly different from that of the semi-transparent map. (3) User experience may cause significant difference in operational efficiency. (4) User experience may cause significant difference in subjective evaluation.

4.4 Procedure

Participants were asked to conduct three wayfinding tasks with increasing difficulty. The first task was the easiest task, which is to judge the farthest profile exhibition area. The second task was a more difficult task, which is to look for the Chinese calligraphy exhibition area and then count the number of calligraphy works. Compared with the first task, participants also needed to look over the details in the exhibition. The third task was the most difficult task, which is to look for all Chinese painting exhibition areas and then point out the longest Chinese painting. Participants needed to memorize and compare the contents in different exhibitions.

The data of operation performance were collected, such as the time required to find each target. After completing all the tasks, each participant was required to fill out a questionnaire regarding their overall satisfaction. The questionnaire was designed based on a 7-point Likert scale. After that, participants' preferences were investigated in the same way.

In addition, participants were also required to fill out the System Usability Scale (SUS) questionnaire in order to investigate their subjective evaluations. The questionnaire was designed based on a 5-point Likert scale anchored by 1: strongly disagree and 5: strongly agree. The higher the scores of SUS, the better usability of the map.

5 Results

5.1 Analysis of Task Operation Time

The data were analyzed using the statistical software SPSS. Table 1 presents the mean task operation time for each independent variable level, while Table 2 shows the ANOVA table from the analysis.

The first task was to find the farthest profile exhibition area. The result of ANOVA indicated that there was no significant effect of map design regarding the Task 1 operation time ($F = 3.658$, $p = 0.064 > 0.05$). The main effect of user experience on the Task 1 operation time was not significant ($F = 3.549$, $p = 0.068 > 0.05$). There existed no significant difference in the interaction effect between the variables of user experience and map design ($F = 0.041$, $p = 0.840 > 0.05$). It indicated that in the easiest task, user experience and the transparency of map did not significantly affect wayfinding performance.

The second task was to know the number of calligraphy works. According to the statistical analysis results acquired in Table 2, the main effect of map design on the Task 2 operation time was significant ($F = 4.533$, $p = 0.040 < 0.05$). The results suggested that the Task 2 operation time for the opaque map ($M = 9.647$, $Sd = 6.038$) was significantly longer than that for the semi-transparent map ($M = 6.386$, $Sd = 3.056$). One possible explanation for this result is that the opaque map covered the partial VE, thus participants cannot recognize their positions. As is shown in Table 2, the main effect of user experience on the Task 2 operation time was not significant ($F = 0.944$, $p = 0.338 > 0.05$). The interaction effect between the variables of user experience and map design were also not significant ($F = 0.145$, $p = 0.706 > 0.05$).

The third task was to look for the longest Chinese painting. Table 2 shows that there was no significant difference in the main effect of map design in terms of the Task 3 operation time ($F = 3.773$, $p = 0.060 > 0.05$). The main effect of user experience on the Task 3 operation time was not significant ($F = 0.304$, $p = 0.585 > 0.05$). It revealed that there existed no significant difference in the interaction effect between the variables of user experience and map design ($F = 2.739$, $p = 0.107 > 0.05$). Even though the last task was most difficult, user experience and the transparency of map did not significantly affect the process of memorizing and comparing information, as participants might already be familiar with the VE.

Table 1. Descriptive statistics of task operation time (s)

Variable		Task 1		Task 2		Task 3		N
		M	SD	M	SD	M	SD	
Map design	The opaque map	7.328	5.693	9.647	6.038	13.239	8.825	20
	The semi-transparent map	4.526	3.506	6.386	3.056	9.105	3.898	20
User experience	Inexperienced users	4.547	2.867	8.760	5.591	10.585	7.356	20
	Experienced users	7.307	6.050	7.272	4.355	11.759	6.872	20

Table 2. Two-way ANOVA of task operation time

Source		SS	df	MS	F	P
Task 1	Map design	78.484	1	78.484	3.658	.064
	User experience	76.148	1	76.148	3.549	.068
	Map design * User experience	.885	1	.885	.041	.840
Task 2	Map design	106.341	1	106.341	4.533	.040*
	User experience	22.141	1	22.141	.944	.338
	Map design * User experience	3.399	1	3.399	.145	.706
Task 3	Map design	170.900	1	170.900	3.773	.060
	User experience	13.783	1	13.783	.304	.585
	Map design * User experience	124.045	1	124.045	2.739	.107

$\alpha = 0.05$, $*p < 0.05$.

5.2 Analysis of Subjective Satisfaction

Participants selected their satisfaction levels for maps according to their subjective opinions on a 7-point scale, with the two end points labeled strong dissatisfaction and strong satisfaction. The descriptive statistics and two-way ANOVA of satisfaction are shown in Tables 3 and 4. The mean value of satisfaction in each group was more than 5, and the mean value of satisfaction (M = 6.250, Sd = 0.927) showed that participants were inclined to be satisfied.

Table 3. Descriptive statistics of subjective satisfaction

Variable		M	SD	N
Map design	The opaque map	6.100	.912	20
	The semi-transparent map	6.400	.940	20
User experience	Inexperienced users	6.000	.918	20
	Experienced users	6.500	.889	20

Table 4. Two-way ANOVA of subjective satisfaction

Source	SS	df	MS	F	P
Map design	0.900	1	0.900	1.174	.286
User experience	2.500	1	2.500	3.261	.079
Map design * User experience	2.500	1	2.500	3.261	.079

The ANOVA revealed no significant main effect for both map design ($F = 1.174$, $p = 0.286 > 0.05$) and user experience ($F = 3.261$, $p = 0.079 > 0.05$). There was also no significant interaction effect between the two factors ($F = 3.261$, $p = 0.079 > 0.05$). It is possible that user experience and the transparency of map did not relate to users' satisfaction.

5.3 Analysis of Subjective Preference

The data on subjective preference were analyzed to find out which map was most acceptable. The questionnaire was designed based on a 7-point scale, with the two end points labeled strongly dislike and strongly like. The descriptive statistics and two-way ANOVA of preference are shown in Tables 5 and 6. The mean value of preference in each group was more than 5, and the mean value of preference ($M = 5.950$, $Sd = 0.986$) showed that the maps were inclined to be acceptable.

Table 5. Descriptive statistics of subjective preference

Variable		M	SD	N
Map design	The opaque map	5.800	.951	20
	The semi-transparent map	6.100	1.021	20
User experience	Inexperienced users	5.800	.951	20
	Experienced users	6.100	1.021	20

Table 6. Two-way ANOVA of subjective preference

Source	SS	df	MS	F	P
Map design	.900	1	.900	.900	.349
User experience	.900	1	.900	.900	.349
Map design * User experience	.100	1	.100	.100	.754

The result showed that there was no significant difference in the main effect of both map design ($F = 0.900$, $p = 0.349 > 0.05$) and user experience ($F = 0.900$, $p = 0.349 > 0.05$). No significant interaction existed between map design and user experience ($F = 0.100$, $p = 0.754 > 0.05$). It showed that user experience and the transparency of map did not affect subjective preference.

5.4 Analysis of SUS

The descriptive statistics and two-way ANOVA of SUS are shown in Tables 7 and 8. The mean value of SUS in each group was above 75, and the mean value of SUS ($M = 84.938$, $Sd = 13.052$) showed that the maps have good usability. Participants have stated in the interviews that the interface is simple and easy to learn.

Table 7. Descriptive statistics of SUS

Variable		M	SD	N
Map design	The opaque map	83.625	14.315	20
	The semi-transparent map	86.250	11.879	20
User experience	Inexperienced users	80.750	14.870	20
	Experienced users	89.125	9.572	20

The result showed that there was no significant effect of map design ($F = 0.433$, $p = 0.514 > 0.05$). The main effect of user experience was significant ($F = 4.412$, $p = 0.043 < 0.05$). Experienced users ($M = 89.125$, $Sd = 9.572$) gave significantly higher SUS values than inexperienced users ($M = 80.750$, $Sd = 14.870$). The reason might be that the experience of using wayfinding maps in VEs was stored in users' LTM. Wayfinding maps were easier for experienced users to learn and use, therefore, experienced users gave a better evaluation than inexperienced users. The effect of interaction was not significant ($F = 0.945$, $p = 0.338 > 0.05$).

Table 8. Two-way ANOVA of SUS

Source	SS	df	MS	F	P
Map design	68.906	1	68.906	.433	.514
User experience	701.406	1	701.406	4.412	.043*
Map design * User experience	150.156	1	150.156	.945	.338

$\alpha = 0.05$, *$p < 0.05$.

6 Discussion

The results regarding operational efficiency revealed that participants performed significantly better by using the semi-transparent map than the opaque map only in the more difficult task which is to locate and review the information. The result confirmed our first hypothesis. The operational efficiency of the opaque map is significantly different from that of the semi-transparent map. The reason might be that the semi-transparent map increased information display and helped users perceive target objects and their positions in VEs. It is in accordance with previous studies which have proposed that the contrast between the main contents and background could make information on maps easier to be recognized in VEs [3, 6].

The statistical results revealed no significant difference between experienced users and inexperienced users in wayfinding performance. Contradicting the third hypothesis, operational efficiency was unaffected by user experience.

The results of this study showed that there existed no significant difference in the interaction effect among the variables of map design and user experience in terms of overall satisfaction and users' preferences. The results generated from the SUS questionnaire showed that experienced users had a significantly better subjective evaluation of interface usability than the inexperienced users. This result indicated that the fourth hypothesis is accepted. User experience causes significant difference in subjective evaluation. Using wayfinding maps in VEs is easier for experienced users. The reason might be that the operation and function of the wayfinding map was consistent with users' experience stored in LTM. The conclusion is in line with previous studies which have proposed that experienced users who know devices well may perform better and have less hesitation in wayfinding [12].

Based on the results generated in this study, there was no statistical significance between the SUS questionnaire results regarding the semi-transparent map and the opaque map. This also contradicted the second hypothesis. The subjective evaluation of the opaque map is similar to that of the semi-transparent map.

7 Conclusion

This study focused on the difference caused by user experience and map design in users' performance and feelings. Participants were satisfied with the maps, and the maps were inclined to be acceptable. Findings suggested that users with the semi-transparent map may conduct significantly better wayfinding performance in a VE than the opaque map. User experience did not significantly affect their wayfinding performance but affect subjective feelings.

Even though the experiment used a museum as the VE, the results obtained in the present study also can be applicable to all VEs, such as education games, virtual tourism and city navigation. Suggestions for further studies on wayfinding map design include a wider range of map element such as size, shape, and color.

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