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The Efficiency and User Experience of AR Walking Navigation Tools for Older Adults

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ABSTRACT

This study investigated the effects of different types of AR-based pedestrian navigation systems and environmental complexity on the navigation performance of older adults. Thirty-six older adults participated in the experiment and used three different AR-based pedestrian navigation systems (landmark-based, route-based, and map-based) in two different levels of environmental complexity (simple and complex) to navigate to a designated destination in a virtual environment. The results showed that participants made fewer navigation errors in the simple environment compared to the complex environment. In addition, when using the route-based AR pedestrian navigation system, the participants had the best navigation performance (task completion time, navigation errors) and user subjective feedback (system usability, cognitive load), followed by the landmark-based AR pedestrian navigation system, and the map-based AR pedestrian navigation system. Furthermore, the study found that participants with higher spatial memory completed the task in less time and made fewer navigation errors. Older adults experienced difficulties in matching their direction with the road direction in the virtual environment. This study provides a reference for improving the age-adaptability of navigation assistance tools and optimizing information prompting methods in complex environments.

Keywords: Older adults, Augmented reality, Navigation tools, Navigation performance, User experience

INTRODUCTION

Navigating in unfamiliar environments is a common problem for people, and the use of navigation tools on smartphones can improve navigation efficiency and help people navigate better. Mobile navigation systems mainly include map-based, voice-based, touch-based, text-based, photo-based, and combinations of these basic types (Rehrl et al., 2012). However, these systems have certain limitations. Map-based navigation systems require users to constantly focus on the screen, causing them to ignore their surroundings (Giannopoulos et al., 2015; Rümelin et al., 2011). The use of electronic map navigation systems is also affected by the size of the device screen, and users may face difficulties in matching the map with the real environment. Voice-based navigation systems are an alternative to map-based systems, but they are not suitable for noisy environments (Montuwy et al., 2018). Converting verbal navigation instructions into spatial navigation knowledge also increases users' cognitive load.

Augmented reality technology is used in pedestrian navigation because it allows users to combine and align virtual objects with real-world objects and enables real-time interaction (Azuma et al., 2001). AR pedestrian navigation prevents users from constantly staring at their phone screens and ignoring their surroundings, reducing the cognitive load and navigation errors caused by switching between the real environment and the screen (Kim & Dey, 2009; Peleg-Adler et al., 2018). In addition, compared to paper maps, participants using head-mounted AR navigation tools and handheld AR navigation tools had shorter navigation times and lower cognitive load, but their memory of the route was poorer (Rehman & Cao, 2016). However, a study comparing AR pedestrian navigation tools with voice and digital map navigation tools found that users spent more time and made more stops on the road when using AR navigation tools, indicating that users need to exert more effort to understand the meaning of the navigation instructions (Rehrl et al., 2012). Furthermore, older adults still face challenges when using AR pedestrian navigation tools, such as difficulty matching virtual instructions in the AR tool with the real environment, especially at intersections with multiple options in the same direction (Tang & Zhou, 2020). Different types of AR pedestrian navigation tools use different virtual cues, and the effectiveness of assistance may vary in different environments. It is currently unclear how older adults experience navigation when using different types of AR pedestrian navigation tools in different environments. Therefore, this study aims to explore the impact of different types of AR pedestrian navigation tools and the complexity of environmental conditions on the navigation experience of older adults. The results of this study provide insights for improving the age-friendliness of navigation assistance tools and optimizing information presentation methods in complex environments.

MATERIALS AND METHODS

Variables

In this study, we conducted a mixed-factor experiment. The independent variables were the type of AR pedestrian navigation system (within-group variable) and the environmental complexity (between-group variable), the experiment sequence of the participants was balanced. The type of AR pedestrian navigation system had three levels: landmark-based AR pedestrian navigation system, route-based AR pedestrian navigation system, and map-based AR pedestrian navigation system. The environmental complexity had two levels: simple and complex, calculated using the following formula:

$$\mathit{environmental\ complexity} = \frac{\sum_{i=1}^{n} \log_2(F_i)}{L}$$

where n represents the number of decision points in the entire route, F_i represents the number of branching roads at the i-th decision point, and

L represents the length of the road. The larger the calculated value, the more complex the environment.

The dependent variables are navigation performance and subjective feedback of the participants. Performance is measured by the number of navigation errors and task completion time, while subjective feedback is measured by system usability and cognitive load.

The covariates include the gender, age, education level, spatial ability, spatial memory, experience with technology products, experience with AR-related products, experience with navigation products, and experience with joystick usage of the participants.

Experimental Prototype and Tasks

In this study, five prototypes were designed (i.e., two levels of environmental complexity + three levels of AR pedestrian navigation system), as presented in Fig. 1. The virtual environment runs on Windows 10 system and the AR walking navigation system runs on Android 9.0 system.

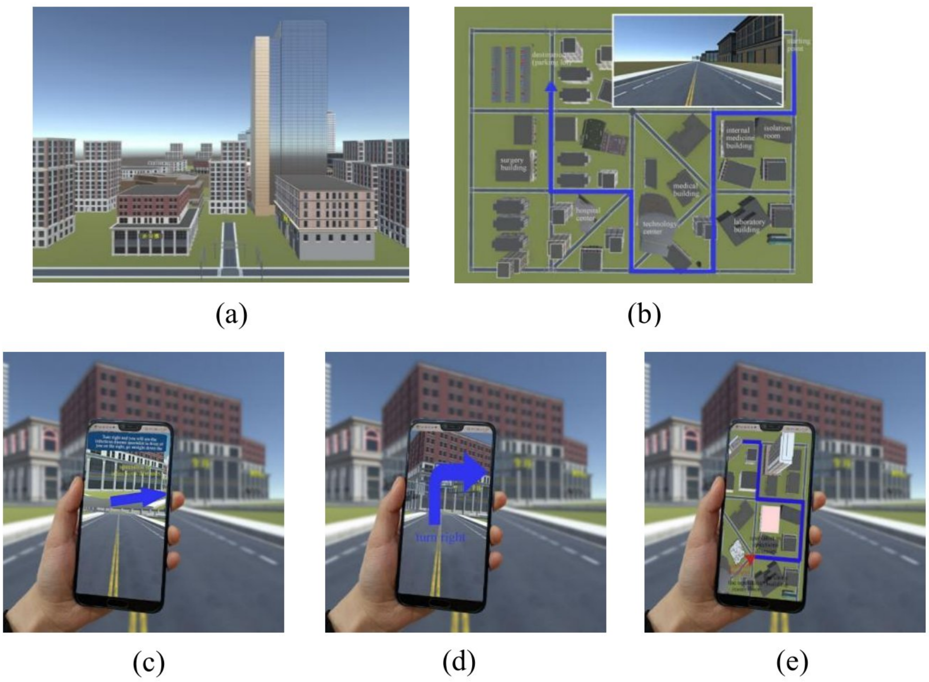


Figure 1: (a) virtual environment (b) top view and front view of the virtual environment (c) landmark-based AR pedestrian navigation system (d) route-based AR pedestrian navigation system (e) map-based AR pedestrian navigation system.

The task for the participants is to use three different AR pedestrian navigation systems to navigate from the starting point to the specified destination based on the prompts provided by the AR pedestrian navigation systems. The timing for each task starts when the participant manipulates the joystick and ends when the participant reaches and sees the destination. If the participant deviates from the specified route during the task, the experimenter will provide a prompt and record the number of times the participant deviates from the route.

Procedure

The experiment required approximately 90 min. Firstly, participants need to complete a joystick test task, where they use the joystick to navigate from the starting point to the endpoint in a road, and the experimenter will record the time taken to complete the task. Participants who can use the joystick properly will then need to complete a background information questionnaire and undergo tests on their spatial memory and spatial abilities. They will then receive training on operating the experimental system until they can independently complete the experimental task. In the formal experiment, participants will be divided into two groups and will need to navigate in a simple or complex environment using a specific type of AR pedestrian navigation system on three predefined roads. They will then complete a "Usability Test" and the "NASA Task Load Index".

RESULTS

Background Information

The demographic information of the participants is shown in Table 1. The spatial ability of the participants ranged from 1 to 11 (M = 5.86, SD = 2.32). The spatial memory of the participants was in the range from 3 to 5 (M = 4.33, SD = 0.59).

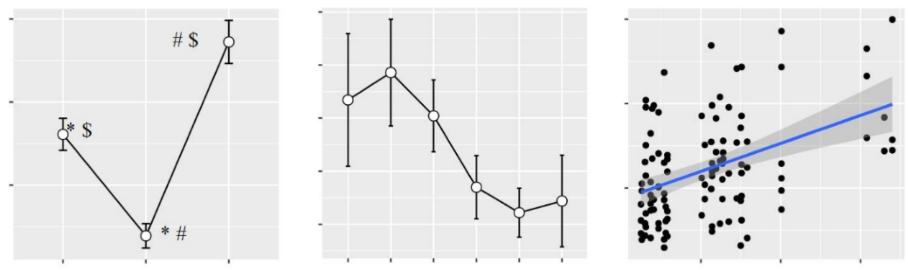
Table 1. Demographic information.

Variable	Category	Num	%
Gender	Female	25	69.4%
	Male	11	30.6%
Education	Primary	7	19.4%
	Middle school	17	47.2%
	High school	10	27.8%
	College degree or above	2	5.6%
Experience using Technology product	With	35	97.2%
	Without	1	2.8%
Experience using joystick	With	1	2.8%
	Without	35	97.2%
Experience using AR-related product	With	1	2.8%
	Without	35	97.2%
Experience using Navigation product	With	9	25%
	Without	27	75%

Performance

Covariance analysis (ANCONA) was used to analyze the effects of the independent variables (environmental complexity and the type of AR pedestrian navigation system) on navigation performance and subject subjective feedback. The gender, age, educational level, spatial ability, spatial memory, experience of using a joystick, and experience of using navigation products of participants were included in the analysis model.

Task Completion Time: During the experiment, one participant failed to complete the task, and the abnormal data was not included in the data analysis. The results of the covariance analysis showed a significant effect of the type of AR pedestrian navigation system on task completion time ($F(2, 94) = 50.56$, $p<0.001$, partial $\eta^2=0.518$, Fig. 2(a)). Post hoc tests using Turkey's HSD revealed that compared to the landmark-based AR pedestrian navigation system, using the route-based AR pedestrian navigation system reduces task completion time by 19.82% (diff = 0.49, $p<0.001$), and using the map-based AR pedestrian navigation system increases task completion time by 21.17% (diff=−0.45, $p<0.001$). Additionally, compared to using the route-based AR pedestrian navigation system, using the map-based AR pedestrian navigation system increased task completion time by 51.12% (diff=−0.93, $p<0.001$). In addition, participants with higher spatial memory had shorter task completion times ($F(1, 94) = 20.17$, $p<0.001$, partial $\eta^2=0.184$, Fig.2(b)), and participants with stronger joystick manipulation skills spent less time finding the destination ($F(1, 94) = 37.74$, $p<0.001$, partial $\eta^2=0.286$, Fig. 2(c)).



(a) (b) (c)

Figure 2: (a) The effect of AR-based pedestrian navigation system on task completion time (b) The effect of spatial memory on task completion time (c) The effect of the ability to use the joystick on task completion time.

The Number of Navigation Errors: The results of the covariance analysis showed that the type of AR pedestrian navigation system had a significant effect on the number of navigation errors ($F(2, 95) = 36.40$, $p < 0.001$, partial $\eta^2=0.434$, Fig. 3(a)). Post hoc tests using Turkey's HSD revealed that compared to the landmark-based AR pedestrian navigation system, using the route-based AR pedestrian navigation system reduced the number of navigation errors by 76.34% (diff = 1, $p < 0.001$), and using the map-based AR pedestrian navigation system increased the number of navigation errors by 87.94% (diff = −1.15, $p < 0.001$). Additionally, compared to using the route-based AR pedestrian navigation system, using the map-based AR pedestrian navigation system increased the number of navigation errors by 694.2% (diff = −2.15, $p < 0.001$). Compared to the simple environment, participants made 58.66% more navigation errors in the complex environment ($F(1, 95) = 8.90$, $p<0.01$, partial $\eta^2=0.086$, Fig. 3(b)). Furthermore, participants with lower spatial memory made more navigation errors($F(2, 95) = 4.30$, $p<0.05$, partial $\eta^2=0.043$, Fig. 3(c)).

Subjective Feedback

System Usability: The results of the covariance analysis showed that the type of AR pedestrian navigation system had a significant impact on participants' evaluation of system usability ($F(2, 97) = 28.70$, $p < 0.001$, partial $\eta^2 = 0.372$, Fig. 4(a)). Post hoc tests using Turkey's HSD revealed that compared to the landmark-based AR pedestrian navigation system, participants' evaluation of the route-based AR pedestrian navigation system increased by 14.25% (diff= −3.92, $p < 0.001$), and their evaluation of the map-based AR pedestrian navigation system decreased by 15.43% (diff = 4.24, $p < 0.001$). Additionally, compared to using the route-based AR pedestrian navigation system, participants' evaluation of the map-based AR pedestrian navigation system decreased by 25.97% (diff= 8.16, $p < 0.001$).

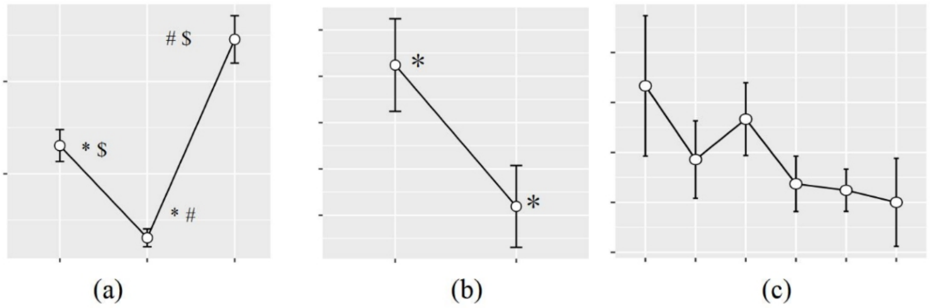


Figure 3: (a) The effect of AR-based pedestrian navigation system on the number of navigation errors (b) The effect of environmental complexity on the number of navigation errors (c) The effect of spatial memory on the number of navigation errors.

The results of the analysis of variance showed that a longer task completion time was associated with lower system usability scores for the participants ($F(1,105)=26.94$, $p<0.01$, $R^2=0.204$). Additionally, a higher number of navigation errors was associated with lower system usability scores for the participants ($F(1,105)=69.89$, $p<0.01$, $R^2=0.400$).

Cognitive Load: The results of the covariance analysis showed that the type of AR pedestrian navigation system had a significant effect on participants' cognitive load ($F(2, 96) = 16.61$, $p<0.001$, partial $\eta^2=0.257$, Fig. 4(b)). Post hoc tests using Turkey's HSD revealed that compared to the landmark-based AR pedestrian navigation system, using the route-based AR pedestrian navigation system reduced participants' cognitive load by 30.71% (diff = 5.81, $p < 0.01$), and using the map-based AR pedestrian navigation system increased participants' cognitive load by 25.53% (diff = 4.83, $p < 0.05$). Furthermore, compared to the route-based AR pedestrian navigation system, using the map-based AR pedestrian navigation system increased participants' cognitive load by 81.16% (diff =−10.64, $p < 0.001$). Additionally, participants with stronger joystick skills had a lower cognitive load in the experiment ($F(1, 99) = 4.61$, $p < 0.05$, partial $\eta^2=0.045$).

Interestingly, participants had a 20.8% higher cognitive load in the simple environment compared to the complex environment ($F(1, 96) = 7.05$, $p<0.01$, partial $\eta^2=0.068$, Fig. 4(c)). Further analysis revealed that participants had a higher cognitive load in the simple environment compared to the complex environment when using the map-based AR pedestrian navigation (diff = 7.28, $p<0.01$, Fig. 4(d)). Analyze the reasons for the result based on the differences in personal characteristics between groups, cognitive load scales, and experimental environment.

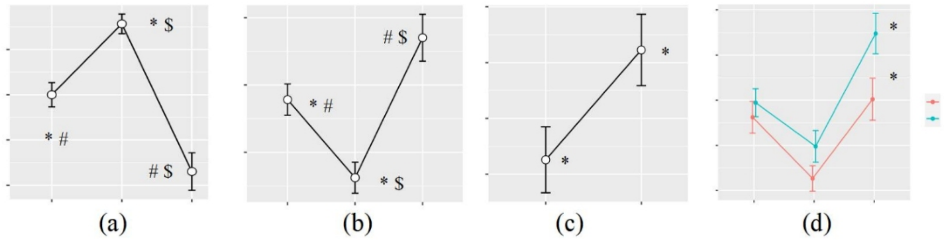


Figure 4: (a) The effect of AR-based pedestrian navigation system on system usability (b) The effect of AR-based pedestrian navigation system on cognitive load (c) The effect of environmental complexity on cognitive load (d) The effect of environmental complexity and AR-based pedestrian navigation system on cognitive load.

The analysis of variance results indicates that there are no differences among participants in terms of age, joystick ability, spatial ability, and spatial memory. Similarly, the logistic regression analysis results show that there are no differences among participants in terms of gender, education level, and experience in using navigation tools. The results are shown in Table 2 and Table 3.

Table 2. Individual differences between groups (1).

Variable	simple		complex		F	p
	M	SD	M	SD		
Age	66.560	4.190	66.060	3.963	0.135	0.715
Experience using joystick	3.004	0.726	3.211	0.939	0.546	0.465
spatial ability	6.110	2.826	5.610	1.720	0.411	0.526
spatial memory	4.500	0.618	4.170	0.514	3.091	0.088

The analysis examined the effects of environmental complexity on the scores of cognitive load dimensions, including mental effort, physical effort, time demand, effort level, task completion satisfaction, and frustration level, as measured by the Cognitive Load Scale. The results of the analysis showed that as environmental complexity became simpler, participants reported higher levels of frustration (F(1, 100) = 5.12, p < 0.05, partial η^2=0.049) and higher levels of effort (F(1, 99) = 6.03, p < 0.05, partial η^2 = 0.057). This suggests that participants perceived a need to exert greater effort to complete the task.

Table 3. Individual differences between groups (2).

Variable	Df	Pearson χ^2	p
Gender	2	0.131	0.717
Education	3	4.756	0.191
Experience using Navigation product	1	1.029	0.310

In terms of the experimental environment, an analysis is conducted on the impact of the number of intersections and the salience of landmarks along the route on the cognitive load of the participants. The formula for calculating the salience of landmarks along the route is as follows:

$$S = \left(\sum_{1}^{n} L_i\right)/n$$

where S represents the salience of landmarks along the route; n represents the number of intersections from the starting point to the destination; L_i represents the visual salience of the i-th decision point landmark. If the landmark is located within the 120° field of view in front of the participant's line of sight and is not obstructed, L_i is equal to 1; otherwise, it is 0. The results of the analysis of variance showed that the fewer the number of intersections on the route, the lower the cognitive load of the participants (F(1,106) = 4.05, p<0.05, partial η^2=0.0368). However, the salience of landmarks did not have a significant impact on the cognitive load of the participants.

Furthermore, when analyzing the relationship between road complexity as a continuous variable and cognitive load, the analysis of variance showed that as road complexity increased, the cognitive load of the participants also increased (F(1, 106) = 6.23, p<0.05, partial η^2=0.056, Fig. 5).

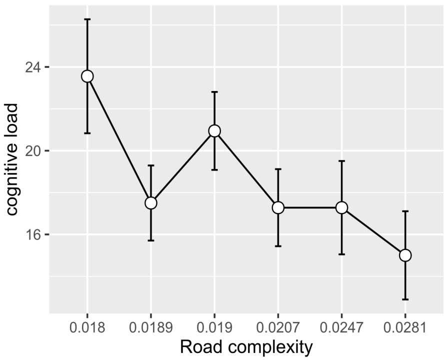


Figure 5: Effect of road complexity on cognitive load.

Based on the analysis results, it is speculated that the cognitive load of the participants is higher in the simple environments compared to the complex environments. This may be due to the higher number of intersections in simple environments compared to complex environments. The higher the number of intersections, the more decisions the participants need to make, leading to an increase in cognitive load.

Finally, a linear regression analysis was conducted to analyze the relationship between performance and cognitive load. The results showed that the longer the task completion time, the higher the cognitive load of the participants ($F(1,105)=20.30$, $p<0.01$, $R^2=0.162$); and the more navigation errors made, the higher the cognitive load ($F(1,105)=29.71$, $p<0.01$, $R^2=0.221$).

Road Direction Matching: During the experiment, it was found that some participants had difficulty matching their own direction of movement in the virtual environment with the direction of the road. Through the analysis of videos of participants performing joystick tasks, it was found that 14 participants (38.9%) were unable to align their direction with the direction of the road during the experiment. Logistic regression analysis was conducted, taking into account the participants' age, gender, education level, spatial ability, and spatial memory. The Forward: LR method was used to select variables that were not related to self-motion perception direction. The results showed that participants with high spatial ability had strong self-motion perception direction ability (OR = 0.637, 95% CI: 0.438-0.928, $p < 0.05$). Furthermore, participants with strong self-motion perception direction ability had strong joystick operation ability ($F(1, 34) = 20.87$, $p < 0.01$, partial $\eta^2 = 0.38$). In addition, it was found that participants with stronger self-motion perception direction ability spent less time on navigation ($F(1, 105) = 11.74$, $p < 0.01$, partial $\eta^2 = 0.101$) and had a lower cognitive load ($F(1, 105) = 5.17$, $p < 0.05$, partial $\eta^2 = 0.047$).

CONCLUSION

For different environments, this study found that participants made fewer navigation errors in the simple environment, but their cognitive load was higher. There could be two possible reasons for this. Firstly, the environmental complexity affects participants' frustration and effort, which in turn affects their cognitive load. The simpler the environment, the more effort participants felt they needed to exert to complete the task, and the more frustrated they became after making mistakes. And it was found that the number of intersections was higher in the simple environment, which may be a contributing factor to the higher cognitive load. In terms of the type of AR pedestrian navigation system, participants performed best in navigation performance and subjective feedback with the route-based AR pedestrian navigation systems, followed by the landmark-based AR walking navigation system, and the map-based AR walking navigation system was the least effective. This is because older adults' spatial abilities mainly focus on landmark knowledge and route knowledge, not configurational knowledge(Goodman et al., 2009; May et al., 2003; Sjölinder et al., 2005; Zhou et al., 2005).

Post-experiment interviews revealed that the route-based AR walking navigation system was found to be more similar to real-life navigation landmarks, making it easier to use. However, the landmark-based AR walking navigation system requires participants to pay attention to the corresponding landmarks, and their relationships with arrow indicators and accompanying text to confirm whether they have made the correct decision. This may lead to navigation errors when participants rely on a single source of information. In terms of personal traits, this study found that participants with high spatial memory levels completed tasks in a shorter time and made fewer navigation errors compared to those with low spatial memory levels. In terms of manipulating the joystick, older adults experienced difficulties in matching their own direction with road direction in the virtual environment. Because the ability of older adults to perceive their own movement direction decreases with age (Warren et al., 1989), but the self-motion perception during navigation is usually based on both body and visual cues (Lester et al., 2017), especially in virtual environments, where users rely more on visual optic flow information. This may affect users' navigation and perception of the environment.

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