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Gender and Age Differences in Using Indoor Maps for Wayfinding in Real Environments

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Abstract: Users more easily become lost in complex indoor environments than in outdoor environments. Users with diverse backgrounds encounter different self-location, route memorization, and route following problems during wayfinding. This study intends to explore gender and age effects on the use of indoor maps for wayfinding in real environments. We used eye-tracking and retrospective verbal protocol methods to conduct a wayfinding experiment in a newly opened building. Statistical data were collected and three findings were obtained. Finding 1: Males had no significant differences with females in indoor self-location, route reading, and route following. However, males paid less visual attention to the landmark and legend than females during route reading. Finding 2: Age-related differences were significant in indoor wayfinding. Younger adults generally outperformed elderly adults in wayfinding in real indoor environments. Finding 3: Gender and age interactive effects were significant in self-location and route memorization. The mean differences of visual attention on the self-location map reading and route memorization between males and females increased with age.

Keywords: indoor wayfinding; eye-tracking; gender effects; age effects; retrospective verbal protocol

1. Introduction

Wayfinding is defined as a purposive, directed, and motivated behavior to efficiently find one's way from an origin to a destination in a familiar or unfamiliar place using sensory cues (maps, signs, and verbal instructions) from the external environment [1,2]. Wayfinding (especially in unfamiliar environments) is a complex, challenging process that requires participants to be aware of their self-location and to orient themselves [3]. Cartographers have paid attention to the influence of map representations on visual attention and user performance in self-location and spatial orientation during wayfinding [4]. Researchers investigating human-centred navigation [5] have looked for ways to redesign cartographical representations to improve the efficiency and effectiveness of wayfinding for users with spatial cognitive difficulties. However, the focus of these studies was outdoor wayfinding [6,7] and an exploratory study on how users accomplish their wayfinding behaviors in indoor environments is a challenging endeavour.

Participants have been found to encounter more spatial cognitive difficulties such as problems acquiring spatial knowledge when reading multi-level indoor maps and getting lost or disoriented at complex turning positions (corners, elevators, and lifts) in indoor environments than in outdoor environments [8,9]. We argue that users still encounter these difficulties with the assistance of maps. Researchers have found that users with different backgrounds have different wayfinding problems because human factors (gender, age, spatial abilities, and expert knowledge) play an important role in the wayfinding process [10,11]. Although the influences of human factors have been extensively researched in outdoor wayfinding experiments, these factors have been ignored in indoor environments. Thus, it is necessary to identify users' individual indoor wayfinding patterns and redesign indoor maps to meet the needs of map users with different backgrounds.

In this article, we aim to investigate the effects of gender and age factors on indoor wayfinding behaviors. Specifically, we focus on the following three questions:

1. Are there differences between males and females in terms of visual attention and user performance in wayfinding in real indoor environments?
2. Are there differences between younger adults and older adults in terms of visual attention and user performance in wayfinding in real indoor environments?
3. Are there any cross effects of the gender and age factors on wayfinding in indoor real environments?

To solve these problems, we conducted an experiment in a newly opened shopping mall. Section 2 presents related work. In Section 3, we present details of a two-factorial (males/females and younger/elderly adults) wayfinding experiment in a real indoor environment. In Section 4, we describe how eye movements and retrospective verbalizations results were recorded to analyze the participants' visual attention and user performance in wayfinding. These quantitative and qualitative results are discussed in Section 5. In Section 6, we answer the above three questions based on participants' indoor wayfinding behaviors and extract some implications that might be helpful to improve indoor map representations for participants with indoor cognitive difficulties.

2. Related Work

2.1. Gender and Age Differences in Wayfinding

Wayfinding is a major area of spatial cognition research that consists of a series of cognitive processes [12]. These cognitive processes include reading a map, remembering the route, finding one's location, and maintaining one's orientation with external features or landmarks. Two behaviors (self-location and spatial orientation) are crucial processes during wayfinding [4]. Self-location refers to identifying one's position in spatial scenery and includes several sub-processes such as map orientation, feature matching, and configuration matching [6]. Spatial orientation is closely related to self-location and refers to determining the direction that one is facing when given an external instruction (cognitive or real maps) [13].

Over the years, both common belief and scientific literature have reported that the sexes differ in their ability to perform spatial and geographic tasks [14] especially in wayfinding or navigation [15]. These research achievements have essential implications for the design of maps and navigation systems. Although it is widely believed that gender differences exist in wayfinding, the research results have not been consistent across different experiments. For example, Tlauka, Brolese, Pomeroy, and Hobbs [16] found that men could more rapidly locate targets in the virtual environment. Andersen, Dahmani, and Konishi [17] reported that, in virtual navigation, gender differences occurred only in environments devoid of landmarks and disappeared in environments containing multiple landmarks However, Liao [4] found that men and women showed slightly significant differences in user performance and visual attention in 3D outdoor environments.

Researchers have also reported that there were age-related differences in wayfinding [18,19] and that such differences were not similar in different wayfinding experiments. Taillade, Sauzéon, and Dejos [20] found that elderly people encountered difficulties in finding landmarks and locating themselves in unfamiliar environments. The elderly participants demonstrated a poor ability to remember a planned route. Adamo, Briceño, and Sindone [21] reported that there were no significant age differences in distance reproduction wayfinding in a virtual environment. Taillade, N'Kaoua, and Sauzéon [22] observed age-related differences in navigation tasks in a real environment. In addition, some researchers have found cross effects of the gender and age factors on wayfinding. For example, Brown and Khanan [23,24] showed that gender-related and aged-related factors could both influence participants' spatial cognitive abilities in laboratory tests or in a virtual environment.

In summary, scientists have shown that age and gender-related factors play important roles in wayfinding but those results differed across experimental settings. Researchers have mainly focused on age and gender-related differences in outdoor environments. It is unknown whether and how far the findings from outdoor environments can be applied to indoor environments. Furthermore, existing studies have employed virtual environments to investigate age and gender differences [25]. Whether these differences occur in a real indoor environment is still a mystery.

2.2. Wayfinding Research in Indoor Environments

It is not easy for participants to find their ways in a complex public building [26]. Thus, scientists have made great efforts to determine participants' indoor wayfinding difficulties. Li and Giudice [27] constructed a multi-level virtual building and found that participants encounter more location and spatial orientation problems without the assistance of map representations. Burigat, Chittaro, and Sioni [28] built a 3D virtual building model to focus on indoor wayfinding problems and found that participants more easily became lost at turning positions and that 3D maps were more helpful than 2D maps in helping people solve orientation problems. Trine and Thorsteinn [29] designed a wayfinding experiment in real-world environments and showed that the type of map appears to be an important determinant of indoor wayfinding performance and should be varied according to age and skill level. Similar results were also found in a real-world library environment [30]. These works showed that people rely on existing indoor navigational aids [31] and that an indoor map is an effective means of reducing the spatial cognition load during indoor wayfinding [32]. Researchers should adjust indoor maps to provide salient and relevant wayfinding information for users with different cognitive difficulties.

To capture indoor wayfinding behaviors efficiently and accurately, researchers have adopted various methods such as questionnaires [33], pose estimation [34], and real-time tracking methods [35] (GoPro, Google Glass, and Eye-tracking). Among these methods, eye-tracking methods have proved to be effective methods for geo-spatial cognition research [36]. Eye-tracking technology can directly capture users' gaze movements and assist researchers in analyzing spatial abilities in both quantitative and qualitative ways [36]. Therefore, there is an increasing interest in using eye tracking for spatial research in recent years. For instance, Liao and Dong [37] used a Tobii T60 eye tracker to detect the wayfinding difference between 3D and 2D map users in a lab environment. They also used eye trackers to analyze gender effects in outdoor wayfinding in the lab [4]. Kiefer [38] focused on utilizing mobile eye-tracking applications to reveal wayfinding difficulties in real-world urban environments. Brügger, Richter, and Fabrikant [39] utilized eye-trackers to investigate how navigation systems could guide users' attention to support spatial knowledge acquisition during real outdoor wayfinding.

Although eye-tracking technologies provide many benefits in wayfinding research, there are also accompanying difficulties that should not be ignored. Eye movement metrics might not be able to determine what strategy a participant is actually using to find his or her way. For instance, users who prefer a direction strategy for orientation will also observe store landmarks while walking along the wayfinding route [40]. Therefore, eye tracking is often combined with questionnaire, interview, and verbal protocol. The retrospective verbal protocol is a method users' verbalizations that their experimental process are collected after they perform a task [41] and this method can provide additional information in wayfinding research. Kinsley, Dan, and Spitler [35] combined GoPro and verbal protocol methods to analyze users' wayfinding and predict their internal decisions in a library. Liao and Dong [4] used eye-tracking and verbal protocol methods to capture spatial orientation performance. In summary, eye-tracking and verbal protocol methods can be helpful for researchers when investigating map users' indoor wayfinding difficulties.

3. Experiment

We designed and conducted a two-task wayfinding experiment. We specifically hypothesize that:

- Males and females have different visual attention regarding the indoor map and environment and males might perform better than females in indoor wayfinding.
- Younger and elderly adults have significant differences in visual attention and younger adults might have better indoor wayfinding performance than the elderly.
- Gender and age effects impact participants' wayfinding behavior.

3.1. Participants

It was important that participants should not have memory problems. We applied the Wechsler Adult Intelligence Scale (WAIS) [41] to test users' memory abilities. Participants who could repeat eight disordered numbers were selected to take part in the experiment. Twenty-two people took part in the experiment, but two of them did not pass the WAIS test. In the end, twenty people participated in the experiment voluntarily. All of them did not ask to read the routes map again during the route following/wayfinding.

The experiment was a two-factorial design: gender (male x female) x age (young x elderly). The participants were divided into an aged adult group and a younger adult group with 5 males and 5 females in each group.

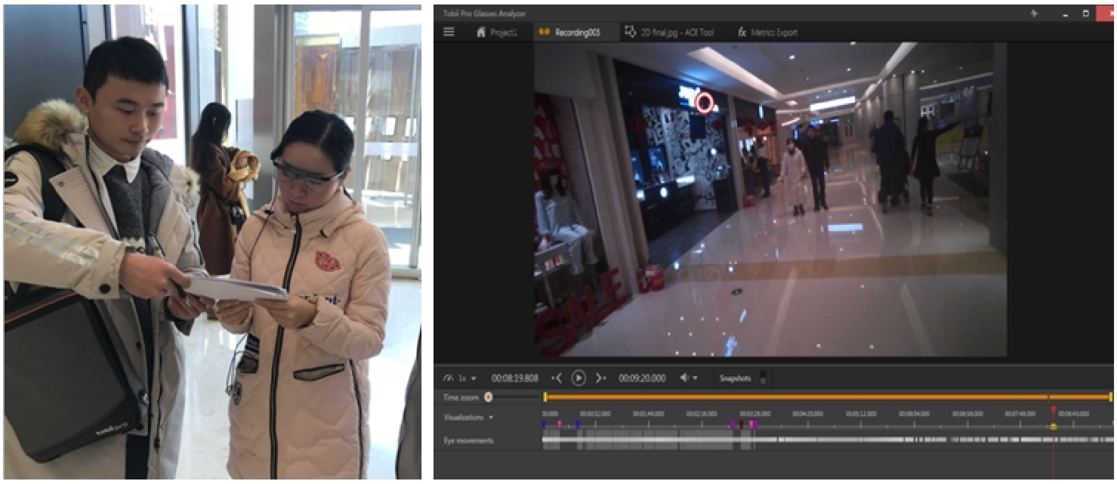
The participants in the aged adult group were aged between 60 and 67 years old (mean age = 62.3, *SD* = 2.50). They held high school graduate (n = 8) or undergraduate (n = 2) degrees and all of them were retired and had no experience in the geo-related field but had used paper maps before. None of them were familiar with the study area.

The participants in the younger adult group were aged between 18 and 29 years old (mean age = 23.1, *SD* = 3.92), they held undergraduate (n = 7) or graduate (n = 3) degrees, and seven of them had experience in non-geo-related fields (three males and four females) while the others majored in geo-related fields. They had all used maps regularly and were not familiar with the study area.

All of the participants had normal or corrected-to-normal vision and could complete the experiment independently. Each participant was given ¥25 (*Yuan*) as a reward. The experiment was reviewed and approved by the local institutional review board (IRB). All of the participants provided their written informed consent to participate in the experiment.

3.2. Equipment

We selected the Tobii Pro Glasses 2 (Tobii AB, Sweden, www.tobii.com) mobile eye tracker with a wide angle HD scene camera (1920 x 1080) and an integrated microphone. The sampling rate of the eye tracker is 50 Hz. It only weights 45 grams, which allows participants to wear the eye-tracker in a flexible way. All participants' sampling rates were above 90%. Tobii Pro Glasses Analyzer software (Figure 1b) was used to manage and analyze eye movement data.



(**a**) (**b**)

Figure 1. Equipment and analyzing application: (**a**) Participant wearing Tobii Glasses 2 in pre-test phase and (**b**) Tobii Pro Glasses Analyzer.

3.3. Materials

As shown in Figure 2, Baidu Indoor Maps (https://ditu.baidu.com/) were selected as the experimental materials. It has been widely used by the general public in China, which guarantee participants have a similar level of familiarity. Baidu Indoor Maps contain all of the detailed cartographic elements, which are essential for users to find task-relevant information.

(a) (b) (c)

Figure 2. Indoor map for wayfinding: (**a**) Indoor map of the 1st floor for Task 1, Routes of 1st floor (**b**) and 4th floor (**c**) for Task 2 and Task 3.

For our real-world indoor experiment, it is important to guarantee that the participants have the same level of familiarity with the study area [42]. Thus, we selected the newly opened shopping mall, Dennis David Mall, as our study environment. Dennis David Mall, in downtown Zhengzhou, China, has a complex indoor environment that includes 11 floors and hundreds of stores.

We selected the Mall's first floor map for Task 1 (described below). Participants were required to point out their location on the map. We chose the 1st and 4th floor for Task 2 and Task 3. A route was highlighted on the map. It began from the starting point A, which is a service counter (first floor), and ended at the destination B known as Fairwhale (a famous shore at the fourth floor). Each map spanned a 450 x 370 m area in the Mall. These materials were presented on a pad during the experiment.

3.4. Procedure

The participants were first welcomed and asked to fill out a form with their background information (gender, age, education, and occupation) and a self-reporting assessment on the pad, which was used to assess the participants' familiarity with the experimental area (familiar or not familiar).

At the pre-test training session, the participants were instructed on how to wear Tobii Glasses 2 to read the indoor map and find the destination at DaShang Mall 100 meters from the experimental shopping mall. The 1-point calibration method was used to calibrate their eyes. Once the participants understood the experimental procedure, they were guided to the Dennis David Mall.

After the pre-test training session, the participants were guided to the experiment area. They were required to complete three tasks in sequence. Before each task, their eyes were checked and recalibrated if necessary. Each participant took approximately half an hour to complete the tasks. Instructions of the tasks are as follows. The participants were told that they would be timed but there was no time limit for all tasks.

Task 1: Self-location: Assume that you are shopping in the Dennis David Mall. Now you are standing somewhere in the Mall. Please read the map on the pad (Figure 1a) and compare it with the surrounding environment to determine where you are. You can turn around but you are not allowed to walk around. Please tell the experimenter where you are and how you can find your location on the map.

Task 2: Route memorization: Now, please read the next two maps on the pad (Figure 1b and 1c). The maps contain the first and fourth floor of the mall. You need to remember the route from A to B on the pad. This is the route you are about to navigate.

Task 3: **Route following / Wayfinding**: Now, you need to walk to the destination following the route you have just memorized. During walking, we will follow with you. If you make an error, we may ask you to stop until you find the destination. If you forget the route, we will provide the map to you. It is important that you do not talk with anyone except the experimenter. After finding the destination, we will replay the eye-tracking video for you and you should recall and speak aloud your thoughts about the wayfinding.

4. Analysis and Results

4.1. Task 1 (Self-location)

4.1.1. Visual Attention on Map Reading

Eye movement metrics were collected to examine how the participants read the indoor map for their self-location. It was labor-intensive to analyze video-based eye-movement data because we allowed the user to freely observe the indoor map and the environment. To facilitate this process, we used the 'automated mapping' function provided by the Tobii Analyzer to match video frames to the static map automatically.

In the self-location phase, each participant was required to stand at a starting position (red point in Figure 3), identify his or her location, and mark the point on the map. To analyze the differences in their self-location behavior, we selected the experimental location area as the area of interest (AOI). The AOI includes a service counter landmark. To account for the imprecision in eye movements, a buffer of 25 pixels (approximately 10 m) was created for aggregation of fixations in the AOI.

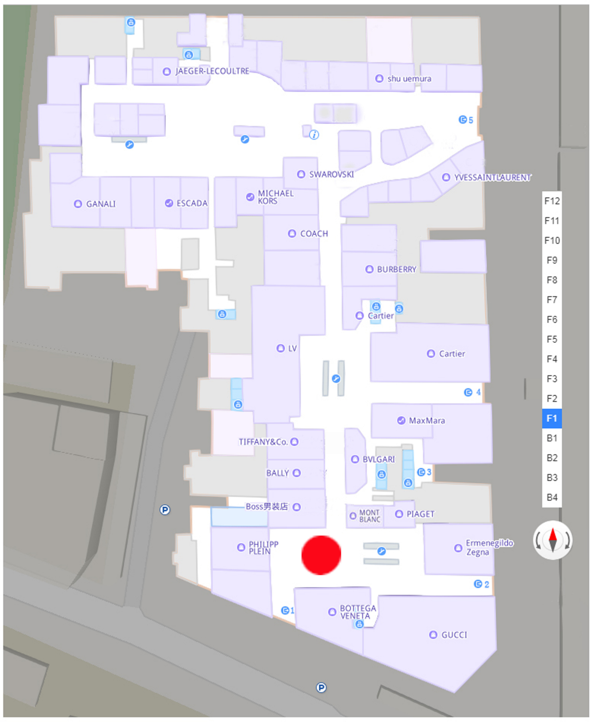


Figure 3. The AOI for self-location: the red point is the area of interest.

Three eye movement metrics (first AOI fixation time, fixation duration, and percent of fixations spent on map) were calculated. Definitions of these metrics are shown in Table 1. We assumed that people with high spatial ability could locate themselves in shorter first AOI fixation time and shorter map reading duration. We employed a two-way ANOVA to examine the differences between groups [43,44] and the results are shown in Table 2.

Table 1. Definition of metrics for analysis of map reading.

Metric	Definition
First AOI fixation time (seconds)	Time before the first fixation on AOI
Map reading duration (seconds)	Total fixation duration on the indoor map
Percent of fixations spent on map (%)	percentage of fixation count on the indoor map

Table 2. Descriptive and inferential statistics for Task 1 (Self-location).

	MALE		FEMALE		Mean (age)		Gender	Age	Gender X Age
Map reading:	M	SD	M	SD	M	SD	ANOVA	ANOVA	ANOVA
First AOI fixation time							$F(1,19) = 1.03$, $p > 0.05$, $\eta^2 = 0.061$	$F(1,19) = 7.25$, $p < 0.05$*, $\eta^2 = 0.312$	$F(1,19) = 9.28$, $p < 0.01$**, $\eta^2 = 0.378$
YOUNGER	18.29	5.01	21.39	7.57	19.84	6.27			
ELDERLY	28.06	11.15	33.08	10.53	30.57	10.56			
Mean (gender)	23.18	9.64	27.23	10.61					
Map reading duration							$F(1,19) = 0.87$, $p > 0.05$, $\eta^2 = 0.051$	$F(1,19) = 8.47$, $p < 0.05$*, $\eta^2 = 0.346$	$F(1,19) = 9.69$, $p < 0.01$**, $\eta^2 = 0.443$
YOUNGER	26.40	9.50	28.50	8.04	27.45	8.37			
ELDERLY	40.96	15.69	50.57	19.78	45.77	17.58			
Mean (gender)	33.68	14.44	39.54	18.39					
% of fixation on map							$F(1,19) = 0.07$, $p > 0.05$, $\eta^2 = 0.004$	$F(1,19) = 0.49$, $p > 0.05$, $\eta^2 = 0.030$	$F(1,19) = 0.93$, $p > 0.05$, $\eta^2 = 0.024$
YOUNGER	0.85	0.07	0.88	0.05	0.86	0.06			
ELDERLY	0.84	0.07	0.83	0.10	0.84	0.08			
Mean(gender)	0.85	0.07	0.85	0.08					

M = mean, SD = standard deviation. **: $p < 0.01$, *: $p < 0.05$.

Table 2 and Figure 4 shows that the first AOI fixation time for males was 23.18 seconds (SD = 9.64) and the results of this metric for females had a mean of 27.23 seconds (SD = 10.61). Males spent 33.68 seconds (SD = 14.44) on average reading the indoor map, which was shorter than the time spent by females who spent 39.54 seconds (SD = 18.39). Males and females spent the same percentage of fixations on the map (M = 0.85). Although Figures 4a and 4b show that females spent more time on first fixation and map reading, the ANOVA results reveal that the gender difference was not significant in the first AOI fixation time ($F(1,19) = 0.57$, $p > 0.05$). The results are similar for the map reading duration ($F(1,19)=0.63$, $p >0.05$) and percent of fixation on the map ($F(1,19) = 0.07$, $p > 0.05$).

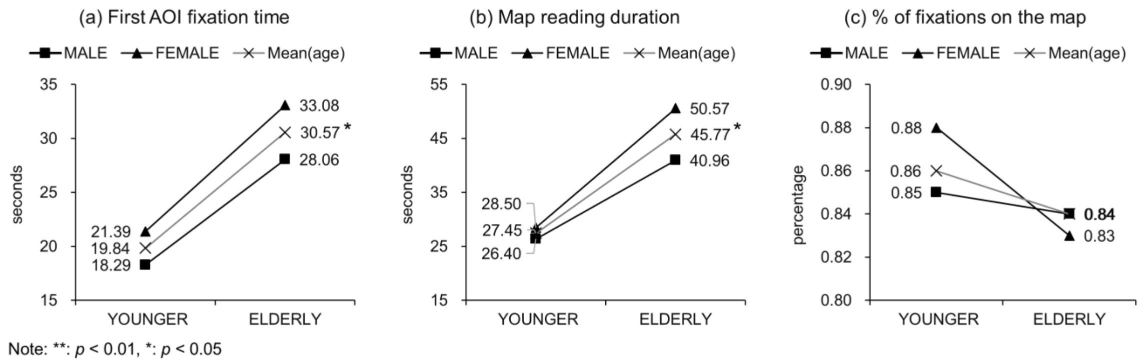


Figure 4. Results of visual attention on map reading in Task 1.

In contrast, statistically significant differences were observed between age groups. ANOVA results indicate that age differences were statistically significant in the first AOI fixation time ($F(1,19) = 7.25$, $p > 0.05$) and the map reading duration ($F(1,19) = 8.47$, $p > 0.05$). The mean values of the first AOI fixation time and the map reading duration in the younger adult group were 19.84 seconds ($SD = 6.27$) and 27.45 seconds ($SD = 8.37$) respectively, which are less than those in the elderly adult group (M = 30.57 seconds, $SD = 10.56$ and M = 45.77 seconds, SD=17.58). However, the difference was not significant in the percent of fixation on the map ($F(1,19) = 0.49$, $p > 0.05$), which indicates that younger and elderly adults spent a similar percentage of fixations on the map (M = 0.86, $SD = 0.06$ and M = 0.84, $SD = 0.08$).

Table 2 shows that gender and age difference was not significant in the percent of fixation on the map. However, the ANOVA result of the first AOI fixation time was 9.28 ($p < 0.01$) and the fixation duration was 9.69 ($p < 0.01$), which proved that the gender and age difference was significant in these variables. In order to find out which factor is differentially effective at each level of a second factor, we selected the Simple Effects Test [45]. Table 3 indicates that the only elderly and gender difference was significant in the first AOI fixation time. Yet, it is clear that both elderly and younger adults were significantly different with a gender factor in the map reading duration.

Table 3. Simple Effects Test for Task 1 (self-location).

			First AOI fixation time			**Map reading duration**		
Gender	Age(I)	Age(J)	MD(I-J)	SE	Sig.	MD(I-J)	SE	Sig.
female	elderly	younger	11.69	5.64	$p > 0.05$	22.07	8.90	$p > 0.05$
male	elderly	younger	9.77	5.64	$p > 0.05$	14.56	8.90	$p > 0.05$
Age	Gender(I)	Gender(J)						
elderly	female	male	5.01	5.64	$p < 0.05$*	9.61	8.90	$p < 0.05$*
younger	female	male	3.09	5.64	$p > 0.05$	2.10	8.90	$p < .05$*

MD = mean difference, SE = standard error. *: $p < 0.05$.

4.1.2. Visual Attention on Landmarks

In Task 1, all participants were asked to stand at the same position (Figure 5a, pink point). They could look around but were not allowed to walk around. A key process for self-location is to match the map objects to the corresponding landmarks in the surrounding environment. In order to analyze what landmarks the participants use to locate themselves, we divided the landmarks into four types (store, elevator, door, and others) and generated AOIs for these landmarks. Examples are shown in Figure 5. We then calculated the fixation durations (in percentage) on these four types of landmarks and the results are shown in Figure 6.

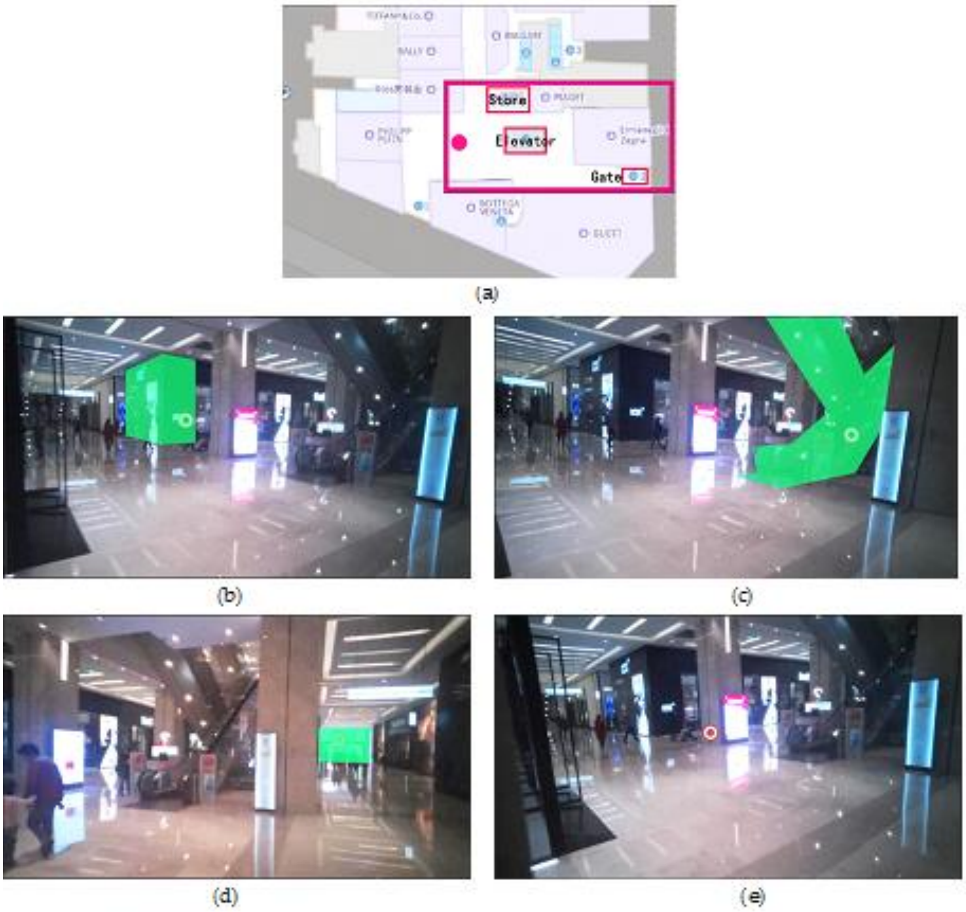


Figure 5. Experiment position and AOI divisions: (**a**) Experiment position and participant's visual field in AOIs, (**b**) AOI of store, (**c**) AOI of elevator, (**d**) AOI of the gate, and (**e**) AOI of others.

For the gender factor, the results revealed that males spent less time on the stores (M = 0.71, SD = 0.15) than females (M = 0.75, SD = 0.07) and that males fixated slightly longer on the elevator (M = 0.09, SD = 0.10) and the door (M = 0.11, SD = 0.10)) than females (M = 0.07, SD = 0.07, M = 0.10, SD = 0.06). However, no significant difference was found across the gender factor (Table 4).

In terms of the age factor, we found that younger adults paid significantly less visual attention to the stores (M = 0.68, SD = 0.12) than elderly adults (M = 0.77, SD = 0.12) with F-test statistics of 0.71, $p < 0.5$. In addition, younger adults also paid significantly less total fixation duration (M = 4.26, SD = 1.93) than elderly adults (M = 8.70, SD = 4.21) with F-test statistics of 8.01, $p < 0.5$. No significant difference was detected in other types of landmarks across age groups (Figure 6).

As for gender and age factors, the only elderly and gender difference was significant in the store fixation time (percentage), according to the Simple Effect Test results ($p < 0.05$*).

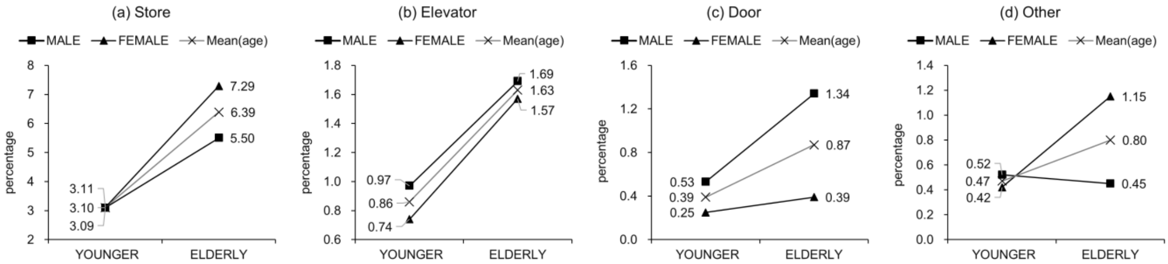


Figure 6. Results of visual attention on landmarks in Task 2.

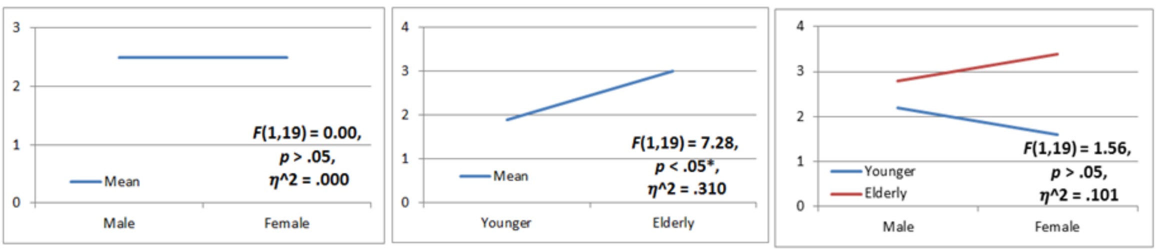
Table 4. Descriptive and inferential statistics for visual attention on the landmark.

Visual attention on landmark	MALE		FEMALE		Mean (age)		Gender	Age	Gender X Age
	M	SD	M	SD	M	SD	ANOVA	ANOVA	ANOVA
Store (in percentage)							$F(1,19) = 0.41$,	$F(1,19) = 0.71$,	$F(1,19) = 0.46$,
YOUNGER	0.68	0.14	0.69	0.09	0.68	0.12	$p > 0.05$,	$p < 0.05$*,	$p < 0.05$*,
ELDERLY	0.75	0.17	0.79	0.06	0.77	0.12	$\eta^2 = 0.025$	$\eta^2 = 0.042$	$\eta^2 = 0.009$
Mean (gender)	0.71	0.15	0.75	0.07					
Elevator (in percentage)							$F(1,19) = 3.34$,	$F(1,19) = 4.68$,	$F(1,19) = 5.25$,
YOUNGER	0.10	0.13	0.08	0.09	0.09	0.10	$p > 0.05$,	$p > 0.05$,	$p > 0.05$,
ELDERLY	0.08	0.07	0.06	0.07	0.07	0.06	$\eta^2 = 0.173$	$\eta^2 = 0.226$	$\eta^2 = 0.247$
Mean (gender)	0.09	0.10	0.07	0.07					
Door (in percentage)							$F(1,19) = 0.05$,	$F(1,19) = 1.89$,	$F(1,19) = 0.99$,
YOUNGER	0.12	0.74	0.16	0.36	0.14	0.10	$p > 0.05$,	$p > 0.05$,	$p > 0.05$,
ELDERLY	0.06	1.09	0.04	0.55	0.05	0.08	$\eta^2 = 0.003$	$\eta^2 = 0.106$	$\eta^2 = 0.034$
Mean (gender)	0.09	0.10	0.10	0.07					
Others (in percentage)							$F(1,19) = 2.84$,	$F(1,19) = 1.12$,	$F(1,19) =1.56$,
YOUNGER	0.10	0.30	0.07	0.16	0.09	0.05	$p > 0.05$,	$p > 0.05$,	$p > 0.05$,
ELDERLY	0.11	0.36	0.11	1.05	0.11	0.04	$\eta^2 = 0.151$	$\eta^2 = 0.065$	$\eta^2 = 0.089$
Mean (gender)	0.11	0.05	0.10	0.06					
Total fixation duration							$F(1,19) = 0.09$,	$F(1,19) = 8.01$,	$F(1,19) =0.39$,
YOUNGER	4.60	1.91	4.12	4.43	4.26	1.93	$p > 0.05$,	$p < 0.05$*,	$p > 0.05$,
ELDERLY	7.98	2.15	9.42	4.37	8.70	4.21	$\eta^2 = 0.006$	$\eta^2 = 0.334$	$\eta^2 = 0.024$
Mean (gender)	6.29	3.67	6.77	4.28					

M = mean, SD = standard deviation. $F(df)$, *$p < 0.05$, $p > 0.05$.

4.1.3. Visual Attention Transitions between the Map and the Landmarks

To evaluate the participants' visual attention transitions between the map and landmark, we defined the Switches: Map<–>Landmark metric as the numbers of attention switches between the map and landmark.Figure 7 shows that males made an average of 2.5 (SD = 1.08) switches between the map and the landmarks, which was the same with females (M = 2.5, SD = 1.27) with F-test statistics of 0.00, $p > 0.05$.



(a) (b) (c)

Figure 7. Visual attention transitions between map and landmark: (**a**) gender differences, (**b**) age differences, and (**c**) gender and age cross differences.

In the age groups, ANOVA results show that the age difference was significant, F (1,19) = 7.28, $p < 0.05$. The elderly adult group made more attention switches between the map and the landmarks (M = 3.0, SD = 1.20) than the younger adult group (M = 1.9, SD = 0.74). There was no significance between the gender and age effects on Switches: Map<–>Landmark, F (1,19) = 1.56, $p > 0.05$.

4.2. Task 2 (Route memorization)

We distinguished three types of AOIs: Route (blue), Landmark (brown), and Legend (yellow) (Figure 8). Route AOIs include the primary route, the start, and the end position. Store AOIs include the store symbol and the name near the route. Store AOIs and Route AOIs do not overlap with each other. However, Route AOIs include some store names such as MUSHIJIU and LALABOBO. Legend AOIs include compass and floor level icons. Fixation durations on these three types of AOIs were calculated.

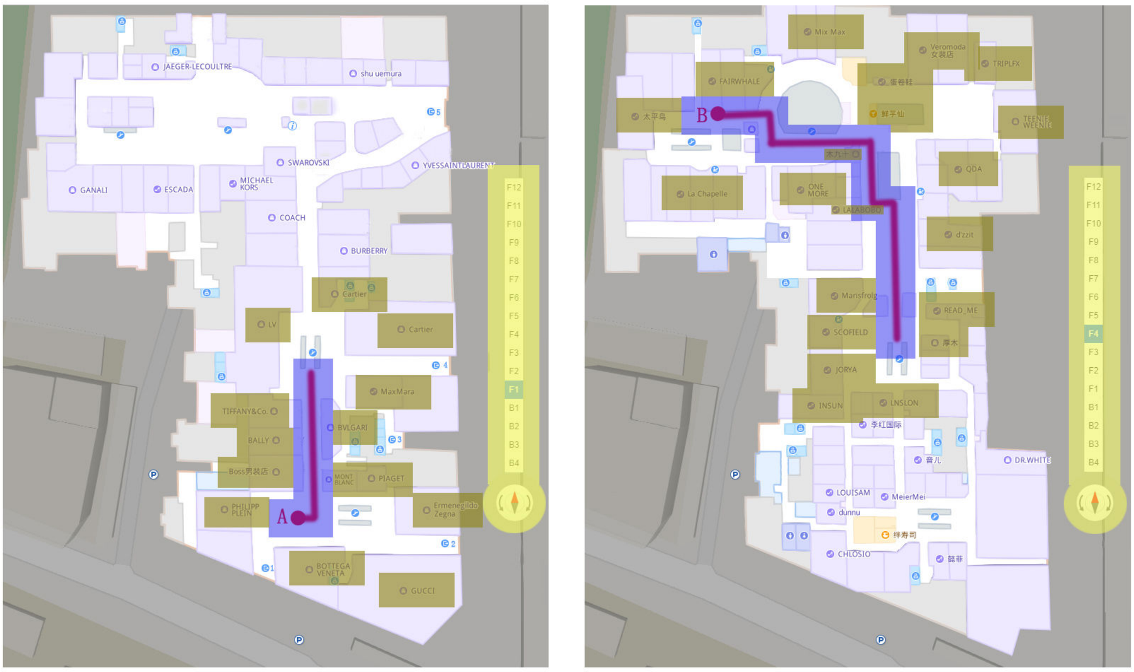


Figure 8. AOI divisions for route memorization.

Table 5 and Figure 9 show the results of fixation durations on different types of AOIs. Males spent significantly less fixation duration on Landmark (M = 15.58 s, SD = 4.82) than females (M = 20.23 seconds, SD = 5.19, F(1, 19) = 8.17, $p < 0.05$), less fixation duration on Legend (M = 8.02 seconds, SD = 2.67) than females (M = 10.34 seconds, SD = 3.57, F(1, 19) = 6.31, $p < 0.05$), but more fixation duration on Route (M = 17.90 seconds, SD = 5.04) than females (M=16.09 seconds, SD = 4.76, F (1, 19) = 1.22, $p > 0.05$). In general, males spent less time on map memorization (M = 42.21 s, SD = 10.35) than females (M = 47.46 s, SD = 12.36), F(1,19) = 2.93, $p > 0.05$.

Differences among age groups are consistent across the three types of AOIs. Elderly adults spent more time on memorizing Landmark (M = 21.34 s, SD = 5.33), Route (M = 20.26 seconds, SD = 3.65) and Legend (M = 11.26 seconds, SD = 2.59) than younger adults (Landmark: M = 14.47 seconds, SD = 2.75, Route: M = 13.73 seconds, SD = 3.60, Legend: M = 7.09 seconds, SD = 2.76). In total, elderly adults had significantly higher fixation duration on map memorization (M = 53.66 seconds, SD = 7.73) than younger adults (M = 36.02 seconds, SD = 6.53). The ANOVA results indicate that differences between younger and elderly adults were statistically significant in these fixation durations ($p < 0.001$).

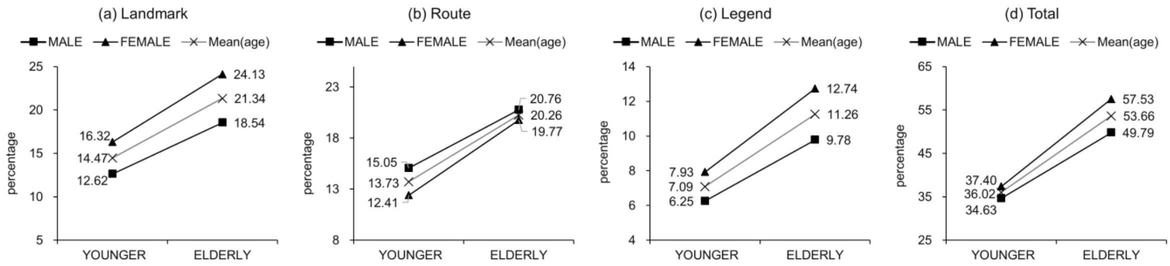


Figure 9. Results of visual attention on different types of AOIs in Task 2.

Table 5. Descriptive and inferential statistics for Task 2 (Route memorization).

Fixation duration	MALE		FEMALE		Mean (age)		Gender	Age	Gender X Age
	M	SD	M	SD	M	SD	ANOVA	ANOVA	ANOVA
Landmark YOUNGER ELDERLY Mean (gender)	 12.62 18.54 15.58	 1.96 5.15 4.82	 16.32 24.13 20.23	 2.14 4.24 5.19	 14.47 21.34	 2.75 5.33	$F(1,19) = 8.17$, $p < 0.05$*, $\eta^2 = 0.338$	$F(1,19) = 17.84$, $p < 0.001$*** $\eta^2 = 0.527$	$F(1,19) = 14.74$, $p < 0.001$***, $\eta^2 = 0.512$
Route YOUNGER ELDERLY Mean (gender)	 15.05 20.76 17.90	 3.58 4.90 5.04	 12.41 19.77 16.09	 3.46 2.30 4.76	 13.73 20.26	 3.60 3.65	$F(1,19) = 1.22$, $p > 0.05$, $\eta^2 = 0.071$	$F(1,19) = 15.81$, $p < 0.001$***, $\eta^2 = 0.497$	$F(1,19) = 0.25$, $p > 0.05$, $\eta^2 = 0.015$
Legend YOUNGER ELDERLY Mean (gender)	 6.25 9.78 8.02	 2.64 1.03 2.67	 7.93 12.74 10.34	 2.89 2.44 3.57	 7.09 11.26	 2.76 2.59	$F(1,19) = 6.31$, $p < 0.05$*, $\eta^2 = 0.283$	$F(1,19) = 18.50$, $p < 0.001$***, $\eta^2 = 0.536$	$F(1,19) = 13.45$, $p < 0.01$**, $\eta^2 = 0.431$
Total YOUNGER ELDERLY Mean (gender)	 34.63 49.79 42.21	 5.92 7.89 10.35	 37.4 57.53 47.46	 7.48 5.90 12.36	 36.02 53.66	 6.53 7.73	$F(1,19) = 2.93$, $p > 0.05$, $\eta^2 = 0.155$	$F(1,19) = 33.11$, $p < 0.001$***, $\eta^2 = 0.674$	$F(1,19) = 15.87$, $p < 0.01$**, $\eta^2 = 0.378$

M = mean, SD = standard deviation. $F(df)$,***$p < 0.001$, **$p < 0.01$, *$p < 0.05$, $p > 0.05$.

We observed significant gender and age interaction effects on landmark (F (1, 19) = 14.74, $p < 0.001$***), legend (F (1, 19) = 13.45, $p < 0.01$**) and total fixation duration (F (1, 19) = 15.87, $p < 0.01$**) (Table 5). Based on Simple Effect Test results, age and gender differences were significant (Table 6). It could also be seen that female factors and age factors were significant in landmark and legend fixation duration.

Table 6. Simple Effects Test for Task 2 (route memorization).

			Landmark			Legend			Total		
Gender	Age(I)	Age(J)	MD(I-J)	SE	Sig.	MD(I-J)	SE	Sig.	MD(I-J)	SE	Sig.
female	elderly	younger	7.85	2.34	$p < 0.05$*	4.87	1.53	$p < 0.05$*	20.73	4.49	$p < 0.05$*
male	elderly	younger	6.10	2.34	$p > 0.05$	3.70	1.53	$p > 0.05$	15.12	4.49	$p > 0.05$
Age	Gender(I)	Gender(J)									
elderly	female	male	5.46	2.34	$p < 0.01$**	3.27	1.53	$p < 0.01$**	7.77	4.49	$p < 0.01$**
younger	female	male	3.71	2.34	$p < 0.05$*	2.10	1.53	$p < 0.05$*	2.17	4.49	$p < 0.01$**

MD = mean difference, SE = standard error. *: $p < .05$, **$p < .01$.

4.3. *Task 3 (Route following)*

4.3.1. General performance

We introduced two metrics to analyze general performance in Task 3 (route following): stop duration and error count. Definitions are shown in Table 7.

Table 7. Definitions of stop duration and error in Task 3.

Metric	Definition
stop duration	The time the participants spent to make a decision at decision points (at elevator and corner)
error count	The number of incorrect decisions the participants made at decision points (at elevator and corner)

The results of the error count at turning positions (C1 ~ C4) and elevators (E1 ~ E2) are shown in Figure 10. It is seen that participants made more errors at the end position than the starting position. They had nine errors at C4 but only two errors at C1. Females showed similar performance with males. Females made fewer errors at C3, C4, and E1 but encountered slightly more trouble at C1 and C2. The difference between the younger and elderly adults was significant. Elderly adults encountered more troubles at C1, C2, C4, E1, and E2. In addition, elderly adults especially elderly females performed the worst during wayfinding because they made errors at C1 and C2 but the others did not show any problems.

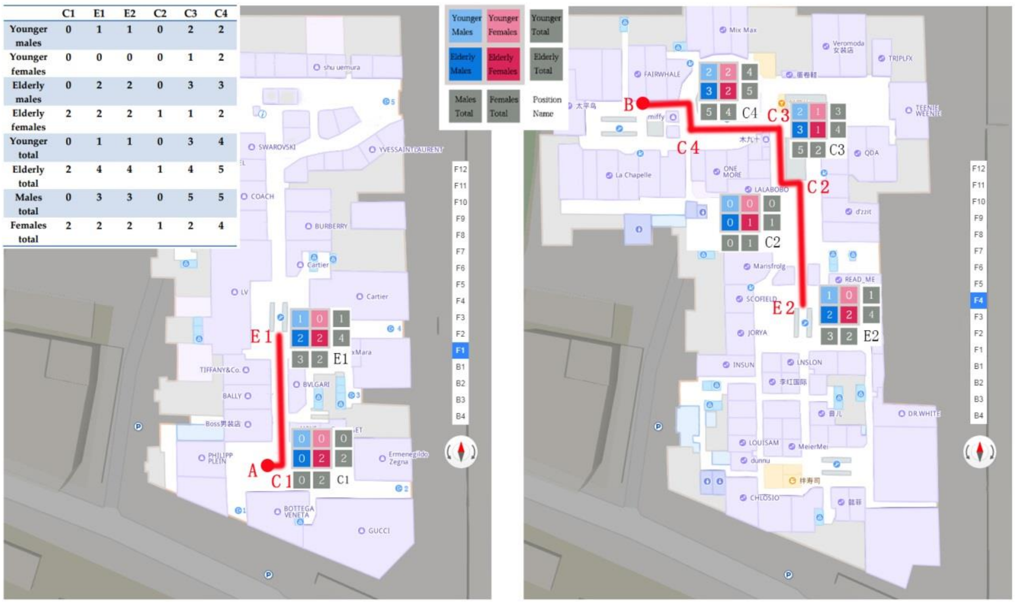


Figure 10. Error counts made by different groups (younger male, younger female, elderly male, and elderly female) at turning positions and elevator.

We further tested the differences quantitatively (Figure 11). Mean stop duration was 0.15 ($p > 0.05$) and mean error count was 0.26 ($p > 0.05$). The results revealed that a gender-related difference was not significant in the route following general performance. Males stopped for 29.89 seconds ($SD = 13.17$), and females spent 31.68 seconds ($SD = 12.85$). In addition, males had more problems at the corner position with 35.83 seconds ($SD = 6.76$) spent at corners, which is 12 seconds more than they spent at elevators (M = 23.95 seconds, $SD = 11.10$).

The Mean stop duration results across age groups indicated that younger adults had much better wayfinding performance than elderly adults. ANOVA results show that significant differences were shown in age-related groups. The difference in the stop duration was significant, $F\ (1,19) = 8.43$, $p < 0.01$. Younger adults only spent 23.86 seconds ($SD = 8.09$) in the stop duration, which is almost 15 seconds less than elderly adults (M = 37.71 seconds, $SD = 12.98$). However, the age-related difference was not significant in the error count, $F\ (1,19) = 3.88$, $p > 0.05$). Younger adults made an average of 0.9 ($SD = 0.70$) errors in corners and elderly adults made 2.0 (SD=1.17) errors.

For gender and age effects, there were no significant differences in the mean stop duration (F(1,19) = 1.22, $p > 0.05$) and mean errors (F(1,19) = 2.24, $p > 0.05$) between gender and age in the spatial orientation process (Table 8).

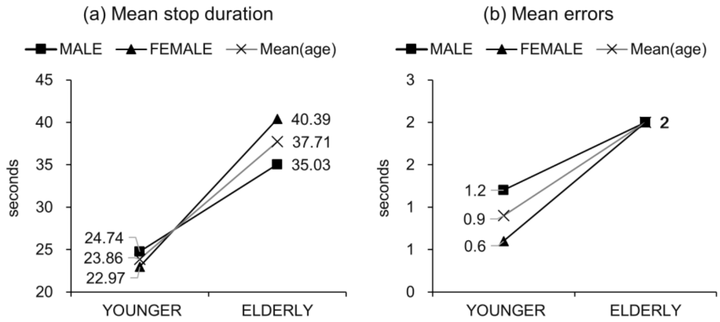


Figure 11. AOI for self-location: the red point is the area of interest.

Table 8. Descriptive and inferential statistics for Task 3 (route following).

	MALE		FEMALE		Mean(age)		Gender	Age	Gender X Age
General performance	M	SD	M	SD	M	SD	ANOVA	ANOVA	ANOVA
Mean stop duration YOUNGER ELDERLY Mean (gender)	 24.74 35.03 29.89	 6.61 16.75 13.17	 22.97 40.39 31.68	 10.07 8.96 12.85	 23.86 37.71	 8.09 12.98	F(1,19) = 0.15, $p > 0.05$, $\eta^2 = 0.048$	F(1,19) =8.43, $p < 0.01$**, $\eta^2 = 0.493$	F(1,19) = 1.22, $p > 0.05$, $\eta^2 = 0.087$
Mean errors YOUNGER ELDERLY Mean (gender)	 1.20 2.00 1.60	 0.89 0.71 0.99	 0.60 2.00 1.30	 0.45 0.84 1.11	 0.90 2.00	 0.70 1.17	F(1,19) = 0.26, $p > 0.05$, $\eta^2 = 0.020$	F(1,19) = 3.88, $p > 0.05$, $\eta^2 = 0.194$	F(1,19) = 2.24, $p > 0.05$, $\eta^2 = 0.036$

M = mean, SD = standard deviation. $F(df)$, ** $p < 0.01$, $p > 0.05$.

4.3.2. Verbal Protocol

We used the verbal protocol to gain additional qualitative insight into the thoughts of the participants. All verbal reports were transcribed and translated into English. The transcripts were then segmented based on the sentence-coding protocol shown in Table 9.

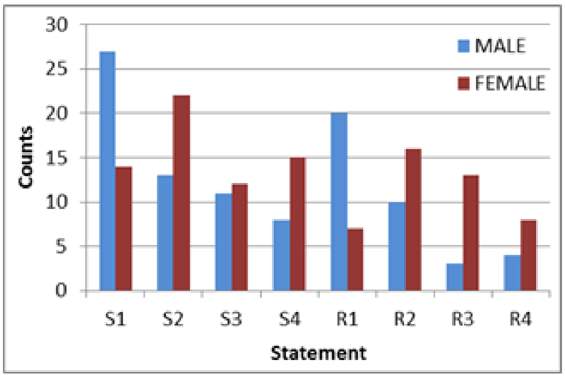
Statement sentences were analyzed based on the positive and negative verbal reports. For instance, the statements were divided into S1S2 (positive statement) and S3S4 (negative statement). If the participants generated more positive sentences, they were considered more confident in their wayfinding behavior. If the participants could not express their wayfinding accurately, they were required to respond to prompts from the experimenters, which indicates that they encountered difficulty in describing their wayfinding process possibly due to a weak understanding of spatial orientation.

Table 9. Sentence classification for the verbal interaction between participants and researchers.

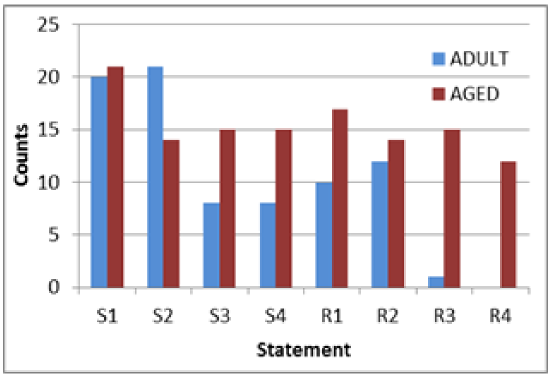
Statement:	**Example(s)**
S1: Positive statement regarding landmarks	This is the LV store near the elevator.
S2: Positive statement regarding direction	I turn left at this corner. I go west at this position.
S3: Negative statement regarding landmarks	Where is the Xian Yuxian store?
S4: Negative statement regarding direction	Should I turn left or right?
Response:	**Example(s)**
R1: Positive response regarding landmarks	Yes, I find the route by recognizing the Xian Yuxian store.
R2: Positive response regarding direction	No, I turn west at this position.
R3: Negative response regarding landmarks	Sorry, I forget the store name.
R4 Negative response regarding direction	Well, I am not sure whether to turn right or left.

The results are shown in Figure 12. We observed that males preferred to use 'left' and 'right' (S1 = 27, R1 = 20) to find their orientation rather than landmarks (S2 = 13, R2 = 10). In contrast, females preferred to use landmarks to find their routes (S2 = 22, R2 = 16) rather than direction (S1 = 14, R1 = 7). It can be assumed that females encountered similar verbal problems as males because females were asked to describe their wayfinding preference (R1 + R2 + R3 + R4 = 38) only slightly more often than males (R1 + R2 + R3 + R4 = 37). However, females had less confidence than males at decision points and females expressed 'not sure' 22 times more than males (S3 + S4 + R3 + R4).

In terms of the age factor, the wayfinding confidence difference between younger and elderly adults was significant but the wayfinding preference difference was quite small (Figure 8b). It is clear that elderly adults encountered more problems in finding their way (S3 + S4 + R3 + R4). In addition, younger adults use 'words of direction' 39 times (S1 + S3 + S5 + S7), which is only two fewer times than those who used landmarks (S2 + S4 + S6 + S8). However, the elderly group preferred to use the direction method to find their way in the experiment since they spoke 68 times about directions (S1 + S3 + S5 + S7), which is 15 times more than about landmarks (S2 + S4 + S6 + S8).



(**a**)



(**b**)

Figure 12. Retrospective verbal protocol results: (**a**) sentence counts between males and females and (**b**) age-related effects on verbal counts.

5. Discussion

In this section, we summarize experimental results and discuss findings about gender and age-related differences in indoor wayfinding.

5.1. Gender Difference

Finding 1: Males had no significant differences with females in indoor self-location, route reading, and route following. However, males paid less visual attention on landmark and legend factors than females when remembering the route.

In general, there was no significant gender difference in indoor wayfinding performance. Males and females had similar effectiveness and efficiency in self-location, route memorization, and route following (Figure 4, Figure 6, Figure 9, and Figure 11). This finding has also been reported by other researchers. For example, Coluccia, Iosue, and Brandimonte [46] found that the significant difference in wayfinding time was not directly due to gender. Harrell, Bowlby, and Hoffarth [47] reported that no gender difference was found in the use of landmarks or buildings to assist in wayfinding.

However, we have observed a difference between males and females in map reading and indoor wayfinding. Males paid significantly less attention to landmarks and legend information than females in route memorization, but they had similar total visual attention on route information (Table 5). Even though Avery [48] and Dogu [49] found that men and women searched shopping landmarks similarly, we found that females paid more visual attention to landmarks. A possible explanation for these divergent results is that females and males adopt different map reading and wayfinding strategies. Chebat and Therrien [50] reported that males tended to find their way by route and direction information, but females preferred to remember the landmarks at corners and then find the correct direction. Babin, Boles, and Griffin [51] concluded that females showed more hedonistic tendencies during wayfinding and hedonistic people were more easily distracted by stores, move more slowly, and stop more frequently. That might explain why females tend to pay more visual attention to landmarks.

5.2. Age Difference

Finding 2: Age-related differences were significant in indoor wayfinding. Younger adults generally outperformed elderly adults in wayfinding in real indoor environments.

The results indicate that younger adults performed better in indoor wayfinding than elderly adults (Table 2, Table 4, Table 5, and Table 8). Our research results clearly show significant age-related differences in self-location, route memorization, and route following in a real-world indoor environment. Such results are widely consistent with those lab-based studies in real outdoor environments [18,19]. For example, Monacelli [52] reported strong age differences in a route-learning task under real hospital conditions. Morganti and Riva [53] observed a greater age-related deficit in spatial cognitive performance.

Two factors might explain why age differences occur. First, due to decreasing spatial cognitive abilities, elderly adults encounter more map reading and wayfinding problems. Taillade, Sauzéon, and Pala [19] reported that elderly adults showed an age-related decline in spatial abilities but did not recognize these problems. Second, indoor environments that contain multiple floors and massive numbers of landmarks within small spaces increase the cognitive burden for the elderly. Adamo, Briceño, and Sindone [21] found that elderly adults might have more spatial problems under complex conditions. Thus, the complexity of the surroundings and spatial cognition decline may explain the age-related differences in indoor wayfinding.

5.3. Gender and Age Difference

Finding 3: Gender and age interactive differences were significant in self-location and route memorization. The mean differences of visual attention on self-location map reading and route memorization between males and females increased with age.

The ANOVA test results show that the interactive effects of the gender and age factors were significant in self-location and route memorization (Tables 2 and 5). Table 2 shows that the interactive effects on first AOI fixation time and map reading duration differences between adult males and females were significant. Similar results were also shown in route remembering fixation duration (Table 5). Rgw Simple Effect Test results present that elderly and younger factors had significant differences with gender factors in the self-location map reading and route memorization process (Tables 3 and 6). In addition, it is obvious that the MD (gender) in younger adults was less than the MD (gender) in elderly adults. The experimental results prove that gender and age factors should not be separated in the research of indoor map reading behavior. In addition, the result reminds designers that we should pay more attention to elderly adults.

It should also be noted that the difference between female and age factors was significant in route remembering (Table 6), but similar results were not found in the other conditions. Considering the previous finding, cartographers should pay more attentions to elderly adults especially female elderly adults in the route remembering process, which might be an important finding to develop indoor maps or navigation.

5.4. Implications to Map Design

Based on the above three findings, we can generate some implications to indoor map design. Finding 2 proves that younger adults significantly outperformed elderly adults. Thus, designers should pay more attention to methods that improve the indoor maps for elderly adults. For example, for elderly adults, cartographers should design a larger size of annotation, brighten the route, and only reserve the landmarks along the route on indoor maps. Indoor navigation systems can be designed to enlarge the size of landmark symbols, which might assist the elderly to acquire spatial knowledge efficiently. In the meantime, designers should delete task-irrelevant landmarks and increase task-relevant landmarks. In addition, Table 8 shows that elderly adults spent significant longer stop duration than younger adults at turning positions. We believe that designers should provide clear information around turning positions for the elderly.

According to Finding 3, female elderly participants spent longer fixation duration than the others in route remembering. Table 5 shows that female elderly adults paid significant longer fixation to landmark and legend factors. In order to improve the efficiency of route remembering, cartographers should decrease the complexity of landmarks and legends. For example, designers can reduce the number of landmarks and only remain essential stores at crucial positions. It might also be better for designers to brighten color or change shapes of point symbols to improve the visibility of the landmarks near the destination and the turnings, which will attract the attention of female elderly adults and assist them in remembering these crucial points.

6. Summary and Further Work

To evaluate gender-related and age-related differences in indoor wayfinding performance, this study employed eye-tracking and retrospective verbal protocol methods to analyze indoor wayfinding behaviors (self-location, route memorization, and route following). Three key findings provide insight into gender and age effects on the use of indoor maps for wayfinding in real environments. According to these findings, we have extracted several implications regarding how to improve the indoor maps' design and navigation. This study could be useful to adjust maps to aid indoor navigation in real-world environments. However, this study used a small number of participants. The participant groups were limited to studying age and gender factors. We cannot generate conclusive implications from the current experiment alone. The universal implications of indoor maps need further investigation.

Future research could include more factors (such as stress [54], culture, occupation, and spatial ability) to represent the variety of user's wayfinding behaviors of a wider variety of users in indoor environments.

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