Evaluation of Wayfinding Performance and Workload on Electronic Map Interface

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Abstract. Electronic map (E-map) is important to support wayfinding, especially for finding unfamiliar routes in the current Web mapping service applications. This study examined the effects of four designing factors including Map Size, Map Type, Direction key, and Zoom function as well as the ability of sense of direction (SOD) and gender differences on the wayfinding performance for a simulated E-map interface. The results indicate that participants with a better SOD would have the faster response time in average and would lower overall workload for target task. Furthermore, participants would have higher workload as the response time is increasing. The interaction effect of SOD and map type would affect the mean response time for target and direction tasks. Participants with good SOD using mixed map have the faster mean response time than ones of poor SOD. For direction task, males with good SOD and good SOD using E-map would have faster mean response time. In addition, both males using mixed map and females using E-map would have faster mean response time.

Keywords: Electronic map (E-map), Wayfinding Performance, sense of direction, NASA-TLX Task Load Index.

1 Introduction

With the advent of advanced spatial information technologies, mobile devices equipped with E-map (electronic map) service applications and/or GPS (Global Positioning System) receivers are common in the daily lives for mobile users. Wayfinding is a cognitive psychological process for finding pathway from an origin to a specified destination [13]. Paper maps have traditionally played major roles in convening spatial information and guiding people around in space. Literature on map learning has shown that using map is not an easy task for children and even for adults [10]. With respect to navigational aids, the study of Ishikawa, et al. [7] examined the effectiveness of GPS-based mobile navigation system in comparison to paper maps and direct experience of routes. Their results showed that GPS users traveled longer distances and made more stops during the walk than map users and direct-experienced

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participants. In addition, various presentation formats of spatial information have been developed, including verbal navigational directions, static maps, interactive maps, 3-D visualizations, animations, and virtual environments [12]. Dillemuth [1] yielded faster travel speed and fewer navigation errors with a generalized map than with an aerial photograph. Some people can readily find their way back to a starting point along a route they have only experienced once, whilst others can only do this with considerable difficulty. Environmental spatial abilities have shown large individual differences [4, 8]. The individual difference between people is so called SOD (sense of direction). The results based on the study of Kato and Takeuchi [9] revealed that good SOD participants (GSD) showed much better performance on route learning than poor SOD participants (PSD). In addition, GSD made more flexible use of effective strategies than PSD. In addition, self-report measures of SOD have been found to predict objective measures of these abilities quite highly [5].

Google Maps and Yahoo! Maps are currently two popular Web mapping service applications. They offer street maps, a route planner for traveling by foot, car, or public transport and an urban business locator for numerous countries around the world. The usability of Google Map and Yahoo! Map interfaces has been evaluated using cross over design and the after-experiment questionnaire for user interface satisfaction (QUIS) [11]. The results of their study indicated Google's E-Map was rated as the highest satisfaction; however, paper map was rated as the lowest satisfaction. There are significant associations between gender and icon recognition. Male participants showed the higher percentage of correct recognition than females.

The functionality of E-map has been greatly advanced by the current technology of interactivity. It can be zoomed in and out, rotated without affecting the ratio of display, as well as easily combined with satellite images, aerial photographs and other sources of information to improve the user's understanding of the geographic database. In this study, the effects of four designing factors on the visual performance for three wayfinding tasks would be examined to provide an optimal user-centered interface for E-map. In addition, subjective assessments of SOD and NASA-TLX task load would be implemented by self-rating questionnaire after experiment.

This study differs from previous ones in that it concentrates on the research concerning designing factors affecting the wayfinding performance. To evaluate the usability of E-map, a simulated E-map interface is designed to collect the response time to complete the tasks of finding a target, identifying qualitative direction, and recognizing qualitative distance. In addition, the correlation between SOD, wayfinding performance, and overall workload would be investigated. The results of quantitative measurements and subjective assessments will be used as the guidelines to provide an ergonomic design and to meet the demands of usability for Web mapping service applications.

2 Method

2.1 Participants

Sixteen undergraduate and graduate students (8 females and 8 males) voluntarily participated in the experiment. Their ages ranged from 21 to 26 years old, with a mean of 24 years and standard deviation of 1.6 years. None of the participants had experience using E-map before the experiment. They all had normal vision or corrected vision reach at least 0.8 and no color-blindness. The requirement to be a participant is to leave alone PC before the formal experiment.

2.2 Materials

Apparatus

There is a 17-inches TFT-LCD monitor (1280×1024 pixels) and Intel(R) Core(TM) 2 Quad CPU Q6600 desktop computer (CPU 2.40 GHz, 1G RAM) with a headphone and a microphone in the laboratory. Optec 2000 Stereo Optical Vision Tester is used to measure vision acuity and examine the color blindness. TAKEI Digital Flicker TK502 is used to measure critical fusion frequency before and after experiment. Macromedia Flash 8 is used to design the simulated E-map interface. In addition, CyberLink Stream Author 3.0 is used to record the process of operating the system during the experiment. A digital video camera recorder (SONY DCR-PC330) is used to record the overall process of experiments and after-experiment questionnaire. In addition, the luminance of experimental lab is 487~611 lux measured by Lutron LX-101 Lux meter.

Design of Simulated E-Map Interface

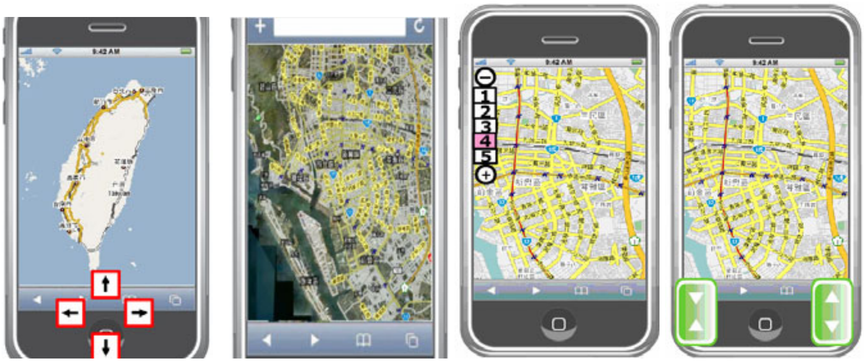
A simulated E-map interface is designed in this experiment. The sources of map images are cited from Google maps [2]. The study area is in the surrounding area of Kaohsiung City, Taiwan. Participant's current position is fixed on the same location as the starting point. The mapped area was dynamically updated as the user moved in space. The starting point and the goals were not always shown together on the map, that is, participant has to move down (head to southern) to the goal location and then use the zooming icons to find the target location. The location of the goal became visible as the user moved on.

The design factors used in the simulated E-map interface including two sizes of map interface (factor "Size", large size for desktop--468x326 pixels vs. small size for mobile device--231x331 pixels), two types of map (factor "Type", E-Map vs. Mixed map,), direction keys (factor "Key", Yes/No,), and hierarchical zoom icons (factor "Zoom", Yes/No). Mixed map means an E-map plus satellite map. The illustration of function of direction key is shown in Figure 1 (a) and 1(b). Figure 1 (a) is an E-map with the traditional up-down direction key and Figure 1 (b) is a mixed map with finger-touch design which means without using the movement of direction key. The illustration of function of hierarchical zoom key is shown in Figure 1(c) and 1(d). Figure 1 (c) is an E-map with traditional zoom icon using +/- and the corresponding numbers and Figure 1 (d) is an E-map with figure-touch design which means without using the clicking icons of zooming in and out.

Sense of Direction Scale

Based on Santa Barbara Sense of Direction Scale (SBSOD) [5], 10 questions of spatial and navigation using Likert's seven-point scale were filled out before the formal experiment. Participants rated each question by circling a number ranging from 1 (strongly disagree) to 7 (strongly agree). Seven out of ten questions are stated positively, e.g., "My sense of direction is very good," "I am very good at reading maps." The other three questions are stated negatively, e.g., "I have a poor memory for where I left things," "I very easily get lost in a new city." The answers will be reversed to positive statement so that a higher score means a better SOD. The relationship of

SOD and response time and the corresponding overall workload would be investigated for three tasks.



(a) (b) (c) (d)

Fig. 1. Illustration of map used in the experiment: (a) E-map with direction key, (b) Mixed map without direction key, (c) E-map with zooming icon, and (d) E-map without zooming icon. Source of map data: Google Map, http:// maps.google.com.tw/.

NASA-TLX Task Load Index

National Aeronautics and Space Administration Task Load Index (NASA-TLX) [3] is used to assess the subjective overall workload for three tasks. A multi-dimensional rating scale is proposed in which information about the magnitude and sources of six workload-related factors are combined to derive a sensitive and reliable estimate of workload. A rating scale of ten-point for six subscales, which consist of mental demand, physical demand, temporal demand, performance, effort, and frustration level. The relative importance of the six component factors to each subject's personal definition of workload was determined in a pretest. All possible pairs (totals 15) of the six factors were presented in a different random order to each subject. The member of each pair selected as most relevant to workload was recorded and the number of times each factor was selected was computed. The resulting values could range from 0 (not relevant) to 5 (more important than any other factor). The more important a factor was considered to be, the more weight the ratings of that factor were given in computing an average weighted workload score (WWL) for each experimental condition. An average of these six subscales, weighted to reflect the contribution of each factor to the workload of a specific activity from the perspective of the rater, is proposed as an integrated measure of overall workload.

2.3 Design of Experiment

An orthogonal array experiment $L_{16}(2^{15})$-- similar to a four-factorial experiment with single replicate will be used to collect the wayfinding performance of visual search. Three tasks will be assigned to each participant, which are (1) to find the targets, (2) to identify the cardinal directions, and (3) to identify the approximate distances. Cardinal directions are based on 8-sectors model (North, East, South, West, North-East, South-East, South-West, and North-West), while approximate distances correspond to a set of ordered intervals that the order among symbolic distance values describes distances from the nearest to the furthest [6]. Time to correctly complete the target task, time to correctly identify the direction task, and time to correctly identify the distance task will be collected based on the simulated E-map interface. Designing factors included (1) Size (Large/Small), (2) Type (E-map/ Mixed map), (3) Key (Yes/No), and (4) Zoom (Yes/No).

2.4 Procedure

At the beginning of the experiment, naive participants were asked to follow the instructions to learn how to operate the simulated E-map interface. They have to practice using the device until they knew how to use it. Before the formal experiment, they were asked to fill out the sense-of-direction questionnaire. One out of sixteen treatment combinations was randomly assigned to one of the participants, and the experimental sessions of wayfinding tasks began. After one of three wayfinding tasks being done, NASA-TLX rating questionnaire was separately filled out by each participant.

3 Results

3.1 Sense of Direction

The self-rating of sense of direction (SOD) is calculated by summing up 10 SOD questions as SOD score. The descriptive statistics are shown in the first row of Table 1. Although the mean SOD of males (43.25) is higher than ones of females (35.1), it is lacking of sufficient evidence to support the gender difference in sense of direction.

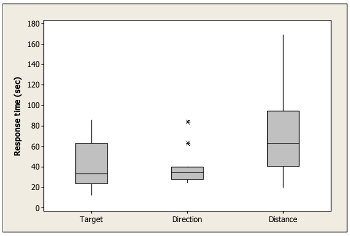
Table 1. Descriptive statistics of SOD, response time (RT), and overall workload (OW) for three wayfinding tasks (n=16)

Variables	Mean	Std Dev	Min	Q_1	Median	Q_3	Max
SOD	39.2	10.4	19.0	34.0	36.5	47.0	56.0
RT of Target[1]	41.1	23.0	12.8	23.9	33.6	63.2	86.0
RT of Direction[1]	38.1	15.3	25.0	27.8	35.0	39.8	84.0
RT of Distance[1]	70.8	38.3	20.0	40.5	63.0	94.5	169.0
OW of Target	6.7	1.6	2.2	5.8	6.9	7.8	9.0
OW of Direction	5.5	1.4	2.2	4.7	5.7	6.6	7.3
OW of Distance	6.0	1.2	3.3	5.4	6.1	6.9	8.0

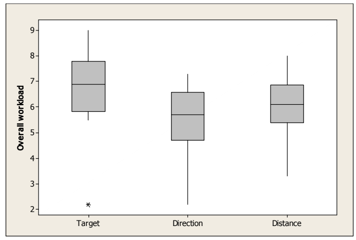
Note 1: the unit of cell is second.

3.2 Wayfinding Performance

Wayfinding performance consists of: (1) response time of correctly finding the targets, (2) response time of correctly identifying cardinal directions, and (3) response time of correctly identifying the approximate distances. The descriptive statistics are shown in Table 1. Mean response times of three wayfinding tasks are significantly different based on two-way ANOVA blocked by participants (F=8.38, p=0.001). Post hoc paired comparisons showed that the mean response time of identifying distance task was longer than that for finding the targets and that for identifying direction (the values shown in the second, third, and forth rows of Table 1 and illustrated in Fig. 2(a)).



(a)



(b)

Fig. 2. Box plots of response time in (a) and NASA-TLX overall workload in (b) for three wayfinding tasks

Based on the self-report scale of sense of direction (SOD), the result of correlation between SOD and response time of three tasks is shown in Table 2. It indicates a moderately negative correlation (r=-0.62, p-value=0.011) between SOD and response time of finding targets, that is, the response time is decreasing as SOD is increasing. However, there are only weakly negative correlation between SOD score and response time of identifying direction as well as identifying distance.

Furthermore, regrouped SOD into two groups--GSD and PSD (named as SODG). The results of ANOVA (Table 3) indicate there is statistically significant interaction effect of SODG *Type (F=5.53, p=0.037). In Fig. 3, the combination of GSD using mixed map has the fastest mean response time (21.56 seconds) for target task.

Table 2. Pearson correlations (r) between response time (RT) and overall workloads for three wayfinding tasks

r	1. SOD	2	3	4	5	6
2. RT of Target	**-0.616***					
3. RT of Direction	-0.277	0.140				
4. RT of Distance	-0.268	0.429	-0.113			
5. OW of Target	**-0.538***	**0.657****	-0.050	0.280		
6. OW of Direction	0.232	-0.381	-0.218	0.170	0.236	
7. OW of Distance	0.275	-0.009	-0.259	0.190	0.480	**0.669****

*p<0.05;**P<0.01

Table 3. ANOVA table for target task

Source of variation	Sum of square	DF	F	p-value
SODG	2894.4	1	27.00	0.000**
Type	3127.7	1	29.18	0.000**
SODG*Type	592.8	1	5.53	0.037*
Error	1286.4	12		
Total	7901.4	15		

*p<0.05;**P<0.01

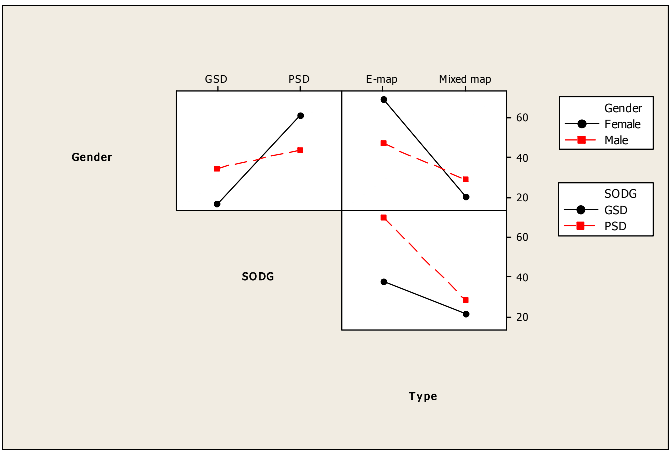


Fig. 3. Interaction plots for target task

Table 4. ANOVA table for direction task

Source of variation	Sum of square	DF	F	p-value
Gender	14.06	1	0.69	0.429
SODG	266.70	1	13.03	0.006*
Type	59.73	1	2.92	0.122
Gender*SODG	284.91	1	13.92	0.005**
Gender*Type	1172.12	1	57.28	0.000**
SODG*Type	1517.25	1	74.15	0.000**
Error	184.17	9		
Total	3498.94	15		

*p<0.05;**P<0.01

The results of ANOVA (Table 4) indicate there are statistically significant interaction effects of Gender*SODG (F=13.92, p=0.005), Gender*Type (F=57.28, p=0.000) as well as SODG *Type (F=74.15, p=0.000). In Fig. 4, male GSD in average has faster response time (30.4 seconds) and GSD using E-map in average has faster response time (28 seconds). In addition, both males using mixed map and females using

E-map in average have faster response time, which is 32.25 and 32.5 seconds, respectively. Participants with a better sense of direction tended to shorter response time in this study. It is similar to the finding of Dillemuth [1]. It would be interesting to see how the ability of sense of direction affects people's wayfinding performance. This is in line with Ishikawa et al. [7] for their map group that a significant relationship between participants' sense of direction and wayfinding performance.

3.3 NASA-TLX Rating

The self-report rating based on NASA-TLX revealed significantly higher overall workload for target task. The descriptive statistics are shown in Table 1. There is a significant difference among the overall workloads of three tasks based on two-way ANOVA blocked by participants (F=5.66, p=0.008). The task of finding the target has the highest overall workload shown in Fig. 2(b). The result of correlation between SOD and overall workload of three tasks is shown in Table 2. It indicates a moderately negative correlation (r=-0.54, p-value=0.032) between SOD and overall workload for target task, that is, the overall workload is decreasing as SOD is increasing. In addition, participants with a slower response time tended to higher overall workload (r=0.66, p-value=0.006) for target task. There is a moderately positive correlation (r=0.67, p-value=0.005) between overall workload of recognizing direction and recognizing distance tasks.

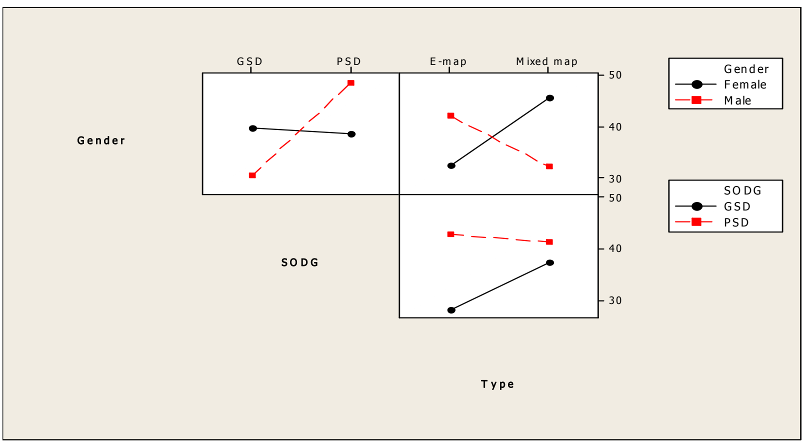
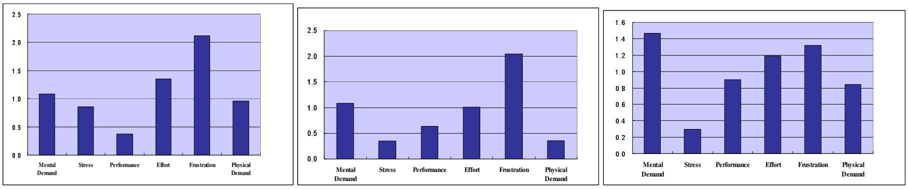


Fig. 4. Interaction plots for direction task

Six subscales including mental demand, physical demand, temporal demand, performance, effort, and frustration level were used to compute weighed task load index. The subscales of frustration, mental workload, and effort are regarded as the most important indices for tasks of finding targets and identifying direction based on the results of NASA-TLX rating scales in Fig. 5(a) and 5(b). However, the subscales of mental workload, frustration, and effort are regarded as the most important indices for task of recognizing distance based on the results of NASA-TLX rating scales in Figure 5(c).



(a) (b) (c)

Fig. 5. Average subjective rating of six workload related subscales for three wayfinding tasks: (a) finding target, (b) identifying direction, and (c) recognizing distance

4 Conclusions

In summary, participants with a better SOD would have the faster response time in average and would lower overall workload for target task. Furthermore, participants would have higher workload as the response time is increasing. The interaction effect of SOD and map type would affect the mean response time for target and direction tasks. Participants with good SOD using mixed map have the faster mean response time than ones of poor SOD. For direction task, males with good SOD and good SOD using E-map would have faster mean response time. In addition, both males using mixed map and females using E-map would have faster mean response time.

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