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Original article

User's Gaze Analysis for Improving Map Label Readability in Way-finding Situation

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Abstract

Map labels are the most recognizable map elements using the human visual system because they are essentially a natural language. In this study, an experiment was conducted using an eye-tracker to objectively record and analyze the response of subjects regarding visual attention to map labels. A primary building object was identified by analyzing visit counts, average visit duration, fixation counts, and the average fixation duration of a subject's gaze for an area of interest acquired using the eye-tracker. The unmarked rate of map labels in Google map, Naver map, and Daum map was calculated. As a result, this rate exceeded fifty-one percent, with the lowest rate recorded for Google map. It is expected that the results of this study will contribute to an increase in the diversity of research in terms of the spatial cognition approach for map labels, which is more helpful to users than the existing body of work on methods of expression for labels.

Keywords : Map Label, Spatial Perception, Eye-Tracking, Digital Map

1. Introduction

For map users, a map is a primary tool and means of acquiring spatial information. Moreover, when this tool is used to identify a path to a location, map orientation is critically required because the surrounding features are determined based on geographic location or vice versa. Moreover, this process includes the psychological activities of acquisition, codification saving, memorization, and recognition of spatial information (Darken and Peterson, 2002). If visually acquired spatial information is memorized, it can be recalled based on a cognitive map or working memory (Mark *et al.*, 1999; Raubal and Worboys, 1999; Frank, 2003). In many cognitive experiments, a specific process that can be used for map reading is identified, and the task performance level of a target subject is evaluated by comparing it with that of another subject. In these methods, an experiment is generally designed to reflect the competence levels of subjects in a specific cognitive process and present a series of tasks or questions (Çöltekin *et al.*, 2010; Moon *et al.*, 2014; Netzel *et al.*, 2017). With questions, objective responses cannot be recorded as presented because they reproduce filtered knowledge about subjects. However, an eye-tracker can be used to objectively record biological response at the time of visual attention for analysis.

According to Raubal (2008), way-finding behavior indicates purpose and direction beginning with an initial point to a specific destination, and it may be motivated by movement, but not directly recognizable by a moving person. For example, a landmark can be a destination, but it may be in a distant location and a moving person may not be able to recognize the landmark during a specific

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duration of the movement. Especially in urban areas, direct cognition is often difficult due to distracting factors such as other skyscrapers and moving people. Kiefer *et al.* (2014) conducted an experiment with eye-traking to reveal the visual matching process between environment and map reading during self-localization in urban area. They found that successful participants put significantly more visual attention to symbols on the map that were helpful in the given situation than unsuccessful participants.

Therefore, we focused on map labels. Among the map elements, a map label represented on a map refers to text information inserted to explain features, it is highly recognizable because it is in natural language. Studies on map labels are mostly about their methods of expression such as their graphic design and the automation of their location (Yoeli, 1972; Imhof, 1975; Wood, 2000; Freeman, 2005; Kern and Brewer, 2008).

As noted by Skupin (2000), an appropriate number of map labels is required depending on the visual complexity. Liao *et al.* (2019) revealed by a controlled experiment, increasing the label density could lead to an increase of the perceived map complexity and a reduced searching efficiency. Label density was strongly associated with the perceived map complexity and response time. But in the real-map experiment, processing real maps for visual search tasks proved more difficult, cognitively more demanding, and less efficient than a controlled experiment. In brief, it is difficult to identify which label should be used to facilitate a better understanding and the correct recognition of information on the users' perspective.

Nevertheless, in this study, we investigate whether there is a gap between the map label representation and user perception by analyzing which features users gaze at using eye-tracker and examining unmarked label rates with simple calculation in major online maps in Korea. As mentioned earlier, maps have a fixed amount of information provided on a scale. In this respect, we want to contribute to the map user what information is more effective for reading the map on a way-finding situation.

In the next section, the concept of eye-tracking are presented to understand collecting data and procedure of a experiment. The analysis results of collected gaze data are presented in Section 3, followed by summary an conclusion in the last section.

2. Measurement of Map Recognition of Objects

2.1 Concept of Eye-tracking

Identifying the factors that influence human cognition to maps and identifying their interrelationships is an important process in judging how humans understand space. Eye-tracking can be used as an approach to measuring objective data. An eye-tracker was selected as an important means of experiment data collection based on the idea that the perception stage whereby an initial stimulus is accepted is an inevitable part of the human knowledge stage and an eye-tracker can record visual perception responses.

Visual attention is the selective focus of attention for the treatment of interesting stimuli, indicating that the attention process and eye-movement are closely related (Duchowski, 2007). In terms of the visual attention, data extracted using an eye-tracker, gaze fixation, pursuit, saccade, and gaze path can be measured(Fig. 1). Gaze fixation occurs when a participant continues to gaze at a certain position; the time of the gaze is defined as approximately 100 ms to 600 ms. Given that gaze is fixed to a location with an object of interest and that attention is directed, it can be identified and used in the analysis of attention level and the gaze phenomenon. Gaze fixation duration refers to the time for information processing or cognition activities, and it can, therefore, be considered that a longer duration implies that information processing is complicated, or cognition activity is difficult. The eyes naturally focus on moving objects, and eye movements can be generated to reaffirm the presence of objects. Such eye movement is called Pursuit. It involves fixing a gaze on the fovea centralis or peripheral vision for a moving object. It is characterized by a movement of less than 30° per second and a duration of 90 ~ 150 ms. Gaze fixation occurs when looking at a static object, but a pursuit occurs when looking at a moving object. If the object moves more than approximately 30°, the pursuit is switched to gaze fixation or saccade. A saccade occurs when a gaze strikes a spot and quickly moves to the next object. The average time is approximately 20~40 ms, and visual information processing is rarely performed during a saccade. Gaze path refers to the path of gaze while looking at an object, and indicates the points at which gaze fixation occurs in chronological order (Duchowski, 2007).

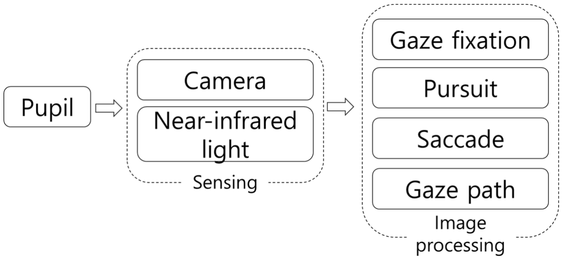

Fig. 1. Concept of eye-tracking

2.2 Experimental Design

The experimental area is part of Hoegi-dong in Seoul, Korea as displayed in Fig. 2. It is a commercial area with buildings of mostly three to five floors and distributed along the lattice road. Also, there exist a specific departure point and a destination in this study and the straight line between the two points is approximately 300 meters. This distance is approximately 400 meters if a participant moves along the road from the starting point to the destination without going backward. The experiment was conducted from December 6th to 28th in 2016. The winter period was chosen to control the experimental environment. In the experimental area, there are many trees along the street, which often block buildings and signboards. This phenomenon is less prevalent during winter.

Fig. 2. Study area

Tobii's Glasses2 eye-tracker was used throughout the experiments and the Tobii Pro Lab program was used to analyze gaze movement data. The data used in the analysis included visit count, average visit duration, fixation count, and average fixation duration of the region of interest. ArcGIS was also used for mapping.

The experimental equipment included a smartphone running Google map for which only enlargement, reduction, and panning were allowed. In addition, the number of marked labels was smaller and the update period was relatively long compared to the Naver and Daum maps, which does not reflect the current situation concerning these three maps. Nevertheless, we chose Google map because the inclusion of excessive labels in an experiment can increase the cognitive load of the user, resulting in more time spent reading information on a map. This experiment was designed for participants to use a map only as an auxiliary tool with a greater emphasis placed on the examination of actual buildings and signs.

Way-finding is affected by the surrounding environmental and individual factors (Montello, 2007; Farr *et al.*, 2012). Several different approaches were considered for way-finding concerning cognitive development, gender difference of spatial perception, interaction with the environment, the familiarity of way-finding environment, and the effect of map learning, and identified several implications (Shin and Lee, 2012). Among the main research topics, many studies have considered gender gap in spatial perception, interaction with the environment, the familiarity of way-finding environment, and the influence of map learning as key control factors of the environment. Therefore, we investigated gender, monthly average visits to the experimental area, average stay time per visit, visit purpose, monthly average use of Google map, and monthly way-finding function use count based on surveys.

The experimental process of this study is represented in Fig. 3. The participants were allowed to move freely to departure points and destinations in each experimental area after being equipped with an eye-tracker. It was not necessary to search for an optimal route. Instead, the stated objective was to examine and identify signs associated with their destination and return. It was also necessary to record a video of the buildings and/or signs referenced on the way to their destination using an eye-tracker.

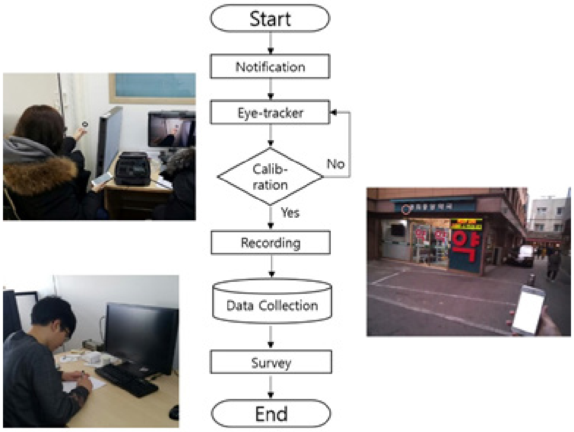

Fig. 3. Experiment process

3. Experimental Analysis and Results

3.1 Characteristics of Participants

There were nine male and eight female undergraduate and graduate student participants from the department of geography at Kyung Hee University. The average age was 25.7 with a standard deviation of 3.69. It took an average of 300.44 seconds (standard deviation of 60.92 seconds) for the participants to complete the task from a starting point to a given destination.

3.2 Results of gaze data

The results obtained from processing the gaze data are displayed in Table 1 and Fig. 4. The average visit count is the number of times a gaze was confirmed to each area of interest and these data were analyzed based on the average visit count of individual areas of interests or buildings. We examined the data in five stages by applying Jenks' natural breaks classification method (de Smith *et al.*, 2018). The average was 1.87 times (standard deviation of 0.45) for the gaze for each area of interest, while less than 1.33 visit counts were recorded for 33 places (24.44%), 1.34 to 1.83 for 40 (29.63%), 1.84 to 2.43 for 34 (25.19%), 2.44 to 3.17 for 23 (17.04%), and 3.18 to 4 for 5 (3.7%). Of the 135 buildings surveyed in the experimental area, there were 28 buildings with 2.44 or more visit counts, of which nine were located on the main street and 19 were on the back road. Excluding the size of roads, there were 12 buildings located at intersections (Fig. 4(a)).

The average visit duration represented the average duration of the gaze on each area of interest and was analyzed based on the average stay duration (seconds) for each individual area of interest (Fig. 4(b)). The gaze for each area of interest lasted for an average of 1.52 seconds (standard deviation of 0.58) and the application of Jenks' natural breaks classification method resulted in 0.5668 seconds or less for 46 places (34.07%), 0.5669 to 1.2226 seconds for 39 (29.63%), 1.2227 to 2.0632 seconds for 34 (24.44%), 2.0633 to 3.2950 seconds for 13 (9.63%), and 3.2951 to 4.9308 seconds for 3 (2.22%).

Fixation count refers to the number of gazes that was fixed on each area of interest for over 60 ms. These data were analyzed based on the average count for each individual area of interest (Fig. 4(c)). The gaze was fixed on each area of interest 5.83 times the average (standard deviation of 1.85) and when examined using Jenks' natural classification method, the results were less than 2.5 times in 31 locations (22.96%), 2.51 to 4.38 times in 42 (31.11%), 4.39 to 7 times in 36 (26.67%), 7.01 to 11.5 times in 21 (15.56%), 7.01 to 11.5 times in 21(15.56%), and 11,51 to 16 times in 5 (3.7%).

The average fixation duration represents the average of the fixation duration time for each area of interest and the average time (seconds) fixed on each individual area of interest was analyzed (Fig. 4(d)). The gaze was fixed on each area of interest for 0.27 seconds on average (standard deviation of 0.10). When applying Jenks' natural breaks classification method, the results were less than 0.1585 seconds for 19 locations (14.07%), 0.1586 to 0.2350 seconds for 33 (24.44%), 0.2351 to 0.3203 seconds for 47 (34.81%), 0.3204 to 0.4851 seconds for 27 (20%), and 0.4852 to 0.7703 seconds for 9 (6.67%).

Table 1. Results of gaze data

Average visit count (times)		Average visit duration (sec.)		Average fixation count (times)		Average fixation duration (sec.)	
Classes	Frequency	Classes	Frequency	Classes	Frequency	Classes	Frequency
1.00 ~ 1.33	33	0.0600 ~ 0.5668	46	1.00 ~ 2.50	31	0.0600 ~ 0.1585	19
1.34 ~ 1.83	40	0.5669 ~ 1.2226	39	2.51 ~ 4.38	42	0.1586 ~ 0.2350	33
1.84 ~ 2.43	34	1.2207 ~ 2.0632	34	4.39 ~ 7.00	36	0.2351 ~ 0.3203	47
2.44 ~ 3.17	23	2.0633 ~ 3.2950	13	7.01 ~ 11.50	21	0.3204 ~ 0.4851	27
3.18 ~ 4.00	5	3.2951 ~ 4.9308	3	11.51 ~ 16.00	5	0.4852 ~ 0.7703	9

Fig. 4. Results of eye-tracking data

3.3 Calculation for Main Fixation Buildings

We calculated the BPI (Building Perception Importance) as given by Eq. (1).

$$BPI = \sum((G_c * G_t) + (F_c * F_t)), \quad (1)$$

where BPI is the Building Perception Importance, G_c is the average gaze visit count, G_t is the average gaze visit duration time, F_c is the average fixation count, and F_t is the average fixation duration time.

Gaze visit count and duration time for a specific area of interest are used to measure the distribution of the users’ interest. The fixation count represents the importance or the amount of attention given. The cognition load is reflected in circumstances where cognition processing is required (Jacob and Karn, 2003; Poole *et al.*, 2005). Average fixation duration refers to instances where the user may encounter difficulty in understanding or the process requires a long time to acquire the relevant information (Just and Carpenter, 1976; Goldberg and Kotval, 1999). Therefore, it represents the user’s attention level to an area of interest. Based on the calculation of the building perception importance values, the data were classified into three stages by applying Jenks’ natural breaks classification method to define relative importance. The values of the low stage were 0.1200 to 2.6934, the middle stage was between 2.6935 and 5.8593, and the high stage was 5.8594 to 11.9751. We considered the high stage group as having the main features (Fig. 5).

Fig. 5. Main features and unmarked buildings

Among the 135 buildings surveyed, the number of main features, which were determined using appropriate analysis, was 27. In the case of Google map (Fig. 5(a)), there were 14 unmarked company names for which a label mark was required. This number was 15 and 16 for Naver and Daum maps, respectively (Fig. 5(b), Fig. 5(c)). However, the locations of the unmarked map labels were different (Table 2, Fig. 5). The ratio of the unmarked features for mid and small roads to those on the main streets from the main gate of Kyung Hee University to the Hongneung direction was 133% in Google map, 114% in Naver map, and 129% in Daum map, indicating a higher unmarked rate for the mid and small roads compared to the main streets. Concerning the unmarked main features found on the main streets, Google and Daum maps failed to display some labels of features located at corners while Naver and Daum maps did not display those at some intersections.

The number of common unmarked features among Google, Naver, and Daum maps was nine, which was the same as the number between Google and Naver maps. This number was 13 for Naver and Daum maps and 10 for Daum and Google maps. (Fig. 6).

Table 2. Ratio of unmarked feature

Map	No. of main features	No. of unmarked features	Ratio of unmarked features (%)
Google	27	14	51.85
Naver	27	15	55.55
Daum	27	16	59.26

Fig. 6. Unmarked features on maps

4. Summary and Conclusion

We examined the basic behavioral characteristics of the participants by conducting surveys including the monthly average visit to the experimental area, monthly average Google map use, and monthly average way-finding function use, which were 1 to 10 times for most groups, while the average stay time per visit was typically less than one hour. The data were based on the experimental items selected during the experimental design to control the environment for analysis, and the experiments were performed after examining the characteristics of the participants based on the different experiments.

Building perception importance was calculated based on the gaze visit count, average visit duration, fixation count, average fixation duration acquired through eye-tracker, and the main features with the highest values were selected by applying Jenks' natural breaks classification method for visualization. As a result, it was determined that the unmarked rate for Google, Naver, and Daum maps were approximately 51.85%, 55.55%, and 59.26% respectively.

Since the results of this study are based on the gaze data for buildings, it is difficult to determine if the marked labels were text on signboards. Building or store names are identified using labels on a Google map, but if there are many signs on a building, we cannot determine with certainty which sign had the greatest impact. As Skupin (2000) indicated, further studies are required to determine what label should be selected when many labels need to be expressed for one feature.

Nevertheless, we expect that this study can contribute to an increase in the diversity of research on map labels as they have been considered only as expression methods to date. We presented a cognitive approach for the investigation of labels that should be more helpful to users.

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