Integration of Aggregated Information and Subjective Experience Through Sequential Information Presentation

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Abstract: Often, when following a pedestrian navigation system, individuals do not remember the route taken or the buildings passed upon arriving at their destination. We hypothesized that by integrating sparsely aggregated information from the problem space into the context of the user's subjective experience, the problem space could be more comprehensively understood from the periphery of the subjective experience. In this study, we tested this hypothesis using pedestrian navigation. Specifically, we proposed a method for mapping aggregated information to subjective experience by incorporating landmarks around the user into the route guidance by a guide agent and sequentially presenting information even at non-decisive points that do not prompt a route change. Experimental results indicated significant differences in "information organization" and "understanding of urban space" in questionnaires. Significant differences were also observed in route memory. The results suggest that the proposed method facilitates the integration of aggregated information to subjective experience.

1 INTRODUCTION

The widespread adoption of smartphones has made pedestrian navigation systems indispensable in daily life. However, conventional systems primarily focus on delivering route and distance information, often leading users to passively follow instructions with a sense of anxiety (Ishikawa et al., 2008; Münzer et al., 2006). This passive reliance can hinder independent information-seeking behavior and negatively impact spatial comprehension and route memory (Willis et al., 2009; Huang et al., 2012). The limited field of view offered by the systems and the reduced attention to the surrounding environment contribute to this.

To address these issues, researchers have proposed incorporating landmarks into navigation guidance (May et al., 2003; Raubal and Winter, 2002). Landmarks serve as crucial directional cues in spatial navigation and play a significant role in human spatial perception (Sorrows and Hirtle, 1999; Caduff and Timpf, 2008). Studies have shown that including landmark information increases user confidence and improves adherence to the suggested path (Ross et al., 2004). Moreover, human spatial cognition relies on three types of spatial knowledge: landmarks, routes, and distance perception (Siegel, 1975; Montello, 1998). While existing navigation systems provide route and distance information, the proper integration of landmark information may enhance memory of urban environments (Richter and Winter, 2014; Schwering et al., 2013). However, current approaches typically provide landmark information only at decision points, such as intersections, neglecting the user's experience in areas where no action choices are required. This approach, while effective in utilizing landmarks as directional cues, may compromise the user's subjective experience in environments with few behavioral changes, such as long straight roads.

To address this limitation, we propose a novel navigation system that sequentially presents information about the surrounding environment along the entire route, including locations without action decisions. This system aims to closely correlate the user's subjective experience with the aggregated navigation information. Specifically, it provides route guidance alongside sequential presentation of information on nearby landmarks and route conditions, thereby enriching the subjective experience by adding contextually relevant information throughout the navigation process. An embodied agent is consistently displayed in the system, offering a degree of empathy and simulating the experience of walking alongside the user.

This study aims to verify whether the proposed system improves the integration of aggregated information from the navigation system with the user's subjective experience through sequential information

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presentation. We will evaluate the impact of our method on users' ability to grasp geospatial information, analyze its effect on route memory, and investigate its influence on users' subjective impressions. By facilitating the integration of aggregated information into subjective experience, our approach seeks to enable a more comprehensive understanding of the problem space from the periphery of the user's experience. This research contributes to the development of more effective and user-friendly pedestrian navigation systems and demonstrates how mapping aggregate information to subjective experience can enhance overall spatial comprehension.

2 RELATED WORKS

Previous research has extensively investigated the impact of mobile navigation systems on spatial memory and cognition. Studies comparing mobile device-based navigation with traditional map-based route finding have consistently shown that the use of navigation systems affects spatial memory and understanding (Ishikawa et al., 2008; Münzer et al., 2006). Ishikawa et al. (2006) found that users of navigation systems tend to develop a bias towards visual memory at the expense of spatial comprehension (Ishikawa and Montello, 2006). Similarly, Munzer et al. (2012) highlighted that navigation systems may impede the formation of cognitive maps (Münzer et al., 2012), while Willis et al. (2009) demonstrated that mobile maps led to decreased acquisition of spatial knowledge compared to paper maps (Willis et al., 2009).

Landmarks play a crucial role in pedestrian navigation and spatial cognition. May et al. (2003) emphasized that landmarks serve as reference points in urban environments, aiding in spatial organization and route selection (May et al., 2003). Sorrows & Hirtle (1999) noted that landmarks contribute not only as directional cues but also to the formation of spatial memory (Sorrows and Hirtle, 1999). Caduff & Timpf (2008) further demonstrated that the presence of landmarks improves path reconstruction performance (Caduff and Timpf, 2008).

The effectiveness of landmarks depends on their distinctiveness and informational value. Stankiewicz & Kalia (2007) pointed out that objects serving as landmarks need to have a distinctive appearance and provide useful information (Stankiewicz and Kalia, 2007). Richter & Winter (2014) found that physical characteristics such as size, shape, and color influence landmark retention (Richter and Winter, 2014). Interestingly, Janzen & van Turennout (2004) showed that objects near decision points are remembered for longer periods, highlighting the importance of context in spatial memory (Janzen and Van Turennout, 2004).

The role of context in memory formation and recall is well-established in cognitive psychology. Tulving & Thomson's (1973) encoding specificity principle demonstrates that context during learning serves as a memory cue (Tulving and Thomson, 1973). Smith & Vela's (2001) meta-analysis confirms the influence of environmental context on memory reproduction (Smith and Vela, 2001). Barsalou (2008) emphasizes that knowledge acquisition and use are closely related to specific situations and contexts (Barsalou, 2008). These theories are applicable to the formation and recall of spatial memory in navigation.

While previous studies have primarily focused on the effects of landmarks at decision points (Rehrl et al., 2010; Anacta et al., 2017), our study proposes a novel approach that promotes the integration of the user's subjective experience with aggregated information. By sequentially presenting information about the surrounding environment at all points, including those that do not require action decisions, we aim to address the assistance dilemma and enhance overall spatial comprehension. This approach extends the concept of "user-centered spatial information provision" proposed by (Schwering et al., 2013) and builds upon the importance of landmark information in navigation instructions, as highlighted by (Anacta et al., 2017). Our method seeks to provide more comprehensive information by mapping aggregated data to the user's subjective experience, potentially facilitating a more holistic understanding of the problem space from the periphery of the user's experience.

In this study, we investigate whether our proposed method can seamlessly integrate subjective experience and aggregated information, as well as examine the secondary effects of this integration on experimental participants. By doing so, we aim to contribute to the development of more effective and user-friendly pedestrian navigation that enhance spatial cognition and memory formation.

3 SEQUENTIAL INFORMATION PRESENTATION

This study proposes an extension to conventional navigation systems, addressing the effective and user-friendly pedestrian navigation by integrating aggregated information with users' subjective experiences. Our approach goes beyond using landmarks solely as directional cues, instead providing sequential information about surrounding buildings and the environment at multiple points along the route, including those not requiring action decisions. This method aims to promote a comprehensive understanding of the problem space by effectively mapping aggregated information to the user's subjective experience. In order to provide a certain degree of empathy, an embodied agent is always displayed in the navigation system and acts as if it is walking with the user.

Our hypothesis states: "Contextual and sequential presentation of information improves geospatial grasp, positively impacts memory retention and information integration of routes traversed, and enhances subjective impressions of navigation."

The proposed system builds upon previous research that primarily focused on using objects near decision points as landmarks. While these methods effectively utilize landmarks as directional cues, our approach extends this concept in two key ways:

Information Provision at Non-Decision Points
We sequentially present supplementary peripheral information at points not requiring action decisions.

Continuous Environmental Understanding
We provide context-sensitive information about the surrounding environment to support ongoing geospatial understanding and increase user confidence in the navigation system.

Our method focuses on contextual information in the user's vicinity, successively presenting engaging information such as names, characteristics, and historical backgrounds. To enhance the usefulness of these objects, we also provide information related to user attributes and destinations. This information is delivered in the most appropriate format (text, images, or audio) based on the user's situation and preferences. An Embodied Conversational Agent, constantly displayed in the navigation system, presents general walking behavior and peripheral information-seeking actions, offering a degree of empathy and simulating the experience of walking alongside the user. The examples of decision point navigation (Decision Navi.) and sequential presentation navigation (Sequential Navi.) are shown in Figure 1.

To verify the effectiveness of our approach, we will conduct pedestrian navigation experiments using the developed system. Participants will be divided into two groups: one using a conventional navigation system and the other using our proposed system. We will analyze and compare both groups' geospatial comprehension, route memory, and subjective impressions of navigation post-experiment. Specifically, we aim to verify that: Spatial comprehension is improved by incorporating virtual city environment objects into navigation and presenting information sequentially and contextually. Sequential information presentation is effective in consolidating route memory and reducing mental workload during navigation.

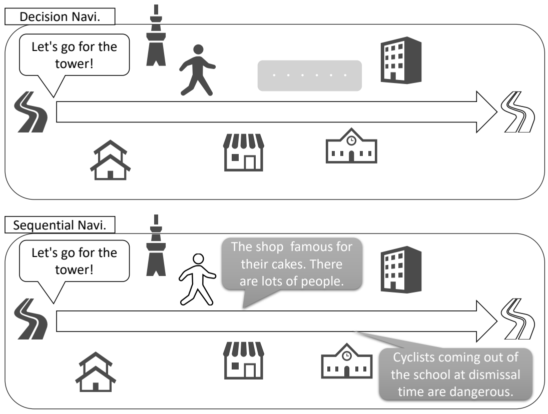

Figure 1: The examples of decision point navigation and sequential presentation navigation.

This methodology aligns with the study's overall goal of investigating whether the proposed system can seamlessly integrate subjective experience and aggregated information, as well as examining the secondary effects of this integration. We address the limitations of previous studies that focused primarily on landmark effects at decision points, extending the concept of user-centered spatial information provision and potentially enhancing overall spatial cognition and memory formation in pedestrian navigation.

4 EXPERIMENT

To validate our hypothesis that integrating contextual objects and presenting sequential information in a virtual urban environment enhances geospatial comprehension and reduces mental workload, we conducted a comparative experiment. This study aimed to address the hypothesis by seamlessly integrating aggregated information with users' subjective experiences, potentially facilitating a more comprehensive understanding of the problem space.

In this experiment, an immersive full-screen monitor was used to simulate a walking situation by creating a virtual urban space on its screen. Participants performed two experimental tasks: an action decision navigation task (DecisionNavi-Task) and a sequential information navigation task (SequentialNavi-Task). In the DecisionNavi-Task, participants aimed at the destination using voice guidance that presents information at the point where action decisions are required, as implemented in existing navigation applications. In the SequentialNavi-Task, participants aimed at the destination using voice guidance that

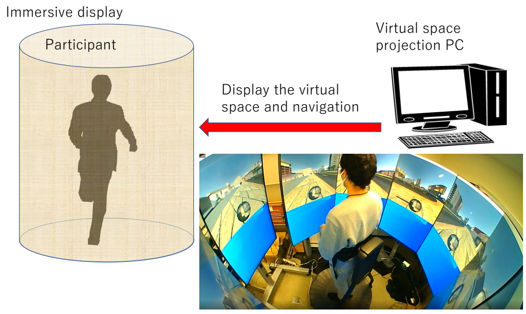

Figure 2: The experimental setting.

presents information including nearby landmarks and contextual information sequentially.

As a subjective measure, 7-point Likert scale questionnaires were asked to participants after the completion of each task to confirm the participant's impressions for the navigation agent. After both tasks were completed, questionnaires were asked to compare and evaluate subjective impressions in both tasks. After the completion of each task, the participants were shown the route they had taken and an image of a certain intersection and asked to draw the direction they should take as an objective measure of their memory of the route and geospatial information.

4.1 Experimental Settings

Participants in the experiment stood on an omni-directional treadmill placed in the center of an area surrounded by an immersive full-screen monitor consisting of 8 displays. Eight displays showed the urban environment, mini-maps, etc. The walking simulator presenting the urban environment was created in unity. Navigation sounds and warnings when deviating from the route guidance were output from the speakers. Walking was controlled by a controller held by the participant. However, they were instructed to perform walking movements on the treadmill in accordance with the screen transitions. A schematic diagram of the experimental environment and the actual experiment are shown in Figure 2.

4.2 Task

Participants in the experiment performed tasks to navigate within a virtual urban environment using two different navigation systems, respectively. In the action-decision navigation, participants followed a guide that directed them in the direction of travel and voice navigation at the point where they needed to make an action decision, and then traveled to the designated destination. In the sequential information navigation, in which sequential information was presented according to the participants' context, the participants moved to the designated destination following voice guidance that presented sequential information on nearby landmarks and contextual information (names, features, history, non-player characters' behavior, time etc.) in addition to the direction of travel. The virtual city map used in each task was different, and each had two transit points. Participants in the experiment relied on the voice guidance and the mini-map displayed on the screen to select a route to reach the destination. In both conditions, the route search took approximately 10 minutes. The map and route used in first task is shown in Figure 3.

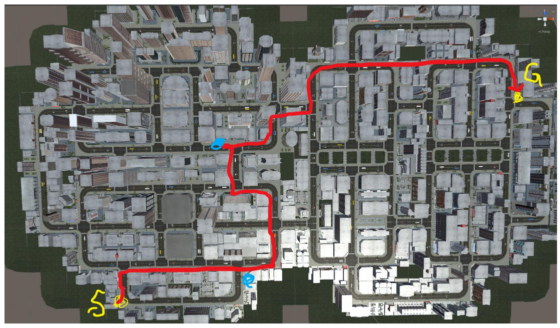

Figure 3: The map and route used in first task.

4.2.1 Navigation

The voice used for navigation was created using text-to-speech software. The timing of the voice was set so that the specified navigation voice would be played when the participants passed a certain point. When participants deviated from the route, they were notified that they had deviated from the route. The navigation audio and the audio when the participant deviated from the route were played at the same volume from the speakers. The navigation features used in each task were as follows.

Action Decision Navigation
Audio navigation is presented at the point where an action decision is required while displaying the direction of travel and distance. The navigation voice is pre-created according to the task. In the task, the navigation was presented approximately once every 25 seconds.

Sequential Information Navigation
In addition to the audio of the action decision navigation, information related to surrounding landmarks is presented at points where no action decision is made. In addition, information about time and the surrounding situation is presented according to the context of the participant. The information presented includes: "There is an apparel store

on the right. It is a little expensive, but it seems to be popular." "There is a cafe on the left side, which seems to be crowded with young people." In the task, navigation is provided approximately once every 15 seconds.

In this experimental setup, audio navigation instructions were systematically pre-recorded and delivered through an automated playback system. The navigational content was dynamically determined based on three key parameters: (1) the participant's current geographic coordinates on the designated task map, (2) the cumulative time elapsed since task initiation, and (3) the specific trajectory patterns observed in the participant's route selection. The temporal frequency of navigational cues was modulated within a predetermined range to maintain optimal information delivery while avoiding cognitive overload.

4.3 Procedure

Participants first entered the experimental environment, surrounded by an immersive monitor, and practiced moving and navigating within the virtual space for about five minutes. Participants were then presented with a picture showing the overall path they would take in the task to see the path. At the same time, they were informed that questions about the path they had taken were prepared for them after each task. After confirming that the participants understood, the first task was performed, and after the task was completed, the participants were asked to note on a map the route they had taken during the task. Then, they were presented with images of three intersections that they had actually passed, and were asked on which direction they should go in order to reach their destination. Afterwards, the participants were asked to complete questionnaires regarding their subjective impressions. After answering the questionnaires, the participants took a short rest. After the rest, a second task was performed, and after the task was completed, the participants were asked to note on a map the route they had taken during the task. The participants were then presented with images of three intersections that they had actually passed, and were asked on which direction they should go in order to reach their destination. Afterwards, the participants were asked to complete questionnaires regarding their subjective impressions. After informing the participants that the all tasks had been completed, they asked to answer questionnaires comparing the tasks.

Twenty-three university students (12 males and 11 females, mean age 20.7 years, SD 1.51) participated in the experiment. Each participant performed two experimental tasks: an action decision navigation task (DecisionNavi-Task) and a sequential information navigation task (SequentialNavi-Task). The order was counterbalanced.

Table 1: Results of subjective impression questionnaires about SequentialNavi and DecisionNavi.

Item	S. Navi (SD)	D. Navi (SD)	p-value
IO	4.3 (1.46)	3.57 (2.06)	.015**
PF	4.78 (1.54)	5.65 (1.47)	.041*
MW	2.52 (1.08)	3.26 (1.96)	.060
DU	4.57 (1.47)	4.22 (2.04)	.425
Uf	5.65 (1.11)	5.39 (1.62)	.479
SE	5.26 (1.86)	2.83 (1.37)	<.001***
DT	4.13 (1.58)	4.30 (2.08)	.762
An	3.04 (1.77)	3.17 (1.83)	.803

*** $p < .001$, ** $p < .01$, * $p < .05$

4.4 Results

We focused on three main areas: subjective impression questionnaires, task comparison questionnaires, and geospatial understanding. These were designed to evaluate the effectiveness of our proposed sequential information presentation method in addressing the hypothesis and enhancing spatial cognition.

4.4.1 Subjective impression questionnaires

Participants responded on a 7-point Likert scale to eight items related to subjective impressions. The items are listed below.

Information Organization (IO): I was able to organize the information from the route guidance by associating it with the scene in front of me.

Passive Feeling (PF): I felt that the route guidance was forcing me to give directions.

Mental Workload (MW): I felt anxiety and worry throughout the task.

Derection Understanding (DU): I understood exactly where I needed to go.

Usefulness (Uf): The information from the route guidance was helpful.

Surrounding Environment (SE): I was able to focus on my surroundings.

Directional Thinking (DT): I was always thinking about my future course.

Annoyance (An): I found the route guidance annoying and depressing.

Wilcoxon signed-rank tests were performed on responses to the DecisionNavi-Task and to the SequentialNavi-Task. Results are shown in Table 1.

Table 2: Results of task comparison questionnaires between the DecisionNavi-Task and the SequentialNavi-Task.

Item	Ave.	SD	v	p-value
PF	-1.39	1.80	33.5	.002**
DU	0.39	2.08	154	.374
USU	1.73	1.32	234	< .001***
PI	1.34	1.43	209	.001**
Im	-0.87	1.86	59.0	.027*
MW	-1.04	1.36	19.5	.004**
SE	2.00	1.13	271	< .001***

*** p < .001, ** p < .01, * p < .05

Wilcoxon signed-rank tests revealed significant differences in three items: ”Information organization” (p = .015), ”Passive feeling” (p = .041), and ”Surrounding environment” (p < .001). The SequentialNavi-Task showed higher scores for information organization and awareness of the surrounding environment, suggesting that our approach successfully integrated aggregated information with users' subjective experiences. Interestingly, participants reported feeling less passive pressure from the navigation system in the SequentialNavi-Task, contrary to potential concerns about information overload.

4.4.2 Task Comparison Questionnaires

Participants responded to their subjective impressions by directly comparing the DecisionNavi-Task and the SequentialNavi-Task on seven items (+3 to -3; positive: SequentialNavi-Task, negative: DecisionNavi-Task). The items are listed below.

Passive Feeling (PF): Which Navi made you feel like you were being forced to follow directions?

Derection Understanding (DU): Which Navi made it easier to understand direction and distance?

Urban Space Understanding (USU): Which Navi made it easier to connect directions and surroundings?

Positive Impression (PI): Which Navi did you like better overall?

Immersion (Im): Which Navi made you more focused on the task?

Mental Workload (MW): Which Navi made you more anxious or worried during the task?

Surrounding Environment (SE): Which Navi made you more aware of your surroundings?

A one-sample Wilcoxon rank sum test was performed for each. The results are shown in Table 2.

Significant differences were found in six out of seven items, with particularly large differences in ”Urban space understanding” (p < .001) and ”Surrounding environment” (p < .001). These results indicate that our proposed method effectively mapped objects in urban space with navigation information, promoting a more comprehensive understanding of the environment. Notably, the SequentialNavi-Task was associated with reduced mental workload (p = .004) and a more positive overall impression (p = .001), supporting our hypothesis that sequential information presentation can alleviate the mental workload.

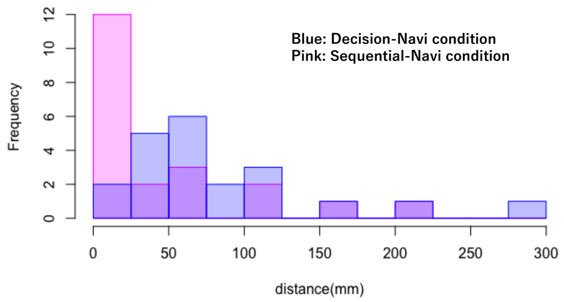

Figure 4: The histogram of the difference from the correct path in the DecisionNavi-Task and SequentialNavi-Task.

4.4.3 Geospatial Understanding

We analyzed the paths walked during the task, which were answered by the participants after each task was completed. Two of the participants did not describe the route correctly, so their data were removed from the analysis. The difference from the correct path was analyzed as the distance of the path drawn off the correct path, and the histogram of the difference from the correct path in the DecisionNavi-Task and SequentialNavi-Task is shown in Figure 4.

In the SequentialNavi-Task, more than half of the participants were able to reproduce the correct path with a difference of less than 25 mm, while in the DecisionNavi-Task, the participants were mostly distributed in the ”difference between 25 mm and 50 mm” and ”difference between 50 mm and 100 mm” categories. This indicates that the SequentialNavi-Task reproduced the correct path relatively well. To verify this result, a corresponding t-test was conducted on the difference from the correct path. The results showed that the group using the proposed system had a significantly smaller difference from the correct path than the group using the conventional navigation system (t(20) = 2.23, p = .037). Furthermore, when asked to indicate correct travel directions at three intersections, the SequentialNavi-Task resulted in a significantly higher percentage of correct answers (Wilcoxon signed-rank test, z = 2.22, p = .033).

These findings collectively suggest that our sequential information presentation method effectively connected participants' subjective travel experiences with objective environmental information. By providing contextual and landmark information throughout the route, not just at decision points, we were able to promote a more comprehensive understanding of the urban space. This approach addresses the limitations of conventional navigation systems that often lead to reduced spatial comprehension and route memory.

5 DISCUSSION

This study examined the impact of route guidance with sequential information presentation on the user's ability to grasp geospatial information and on reducing the user's mental workload for navigation. Experimental results showed that the proposed method was superior in several important respects compared to voice guidance that presents navigation at locations requiring action decisions.

The significant differences found in the subjective evaluation measures of "organizing information" and "understanding urban space" suggest that the proposed method may promote spatial cognition. This is consistent with the contribution of landmarks to spatial memory formation noted by Sorrows & Hirtle (1999) (Sorrows and Hirtle, 1999), and supports the promotion effect of spatial configuration understanding shown in the study by May et al. (2003) (May et al., 2003). Significant differences were also observed in the objective evaluation measures of path reproduction and directional judgment, suggesting that the proposed method contributes to actual spatial memory and directional sense. It is possible that the proposed method can alleviate to some extent the decline in spatial grasp when using navigation systems, as pointed out by Ishikawa et al. (2008) (Ishikawa et al., 2008). These results suggest that the proposed method is effective in improving geospatial understanding and memory by effectively linking the user's subjective travel experience and objective environmental information.

The significant difference in the "Mental workload" item indicates that the proposed method has the potential to reduce users' mental workload. This suggests the possibility of reducing the increased mental workload of using mobile maps reported by Willis (2005) (Willis et al., 2009). Significant differences in the "Surrounding environment" and "Passive feeling" items indicate that the proposed method promotes active environmental awareness. This suggests that the proposed method may improve the decreased attention to the environment when using the navigation system, which was pointed out in previous studies (Münzer et al., 2006; Willis et al., 2009; Huang et al., 2012). The significantly lower immersiveness of the proposed method suggests that the proposed method reduces this problem while still providing an effective spatial understanding.

Meanwhile, the lack of significant differences in "Direction understanding " is inconsistent with the results of the study by Raubal & Winter (2002) (Raubal and Winter, 2002). This may be due to the simplicity of the road structure in the experimental environment. Verification in a more complex environment is needed.

There are some of the limitations and future works of this study. The first relates to the experimental environment. As this experiment was conducted in a virtual urban environment, it is necessary to verify the effectiveness of the proposed system in a real urban environment. In a real urban environment, there are many factors to consider, such as traffic conditions and weather conditions, so the effectiveness of the proposed system in more complex situations needs to be verified. The second concerns the design of the navigation system. In this study, the system's interface had only the minimum elements for navigation. In addition, the behaviour of the navigation agents was only a rule-based output of general behaviour. It is necessary to consider ways of presenting information that are tailored to the attributes of the user and the characteristics of the task. For example, it is necessary to select the most appropriate information presentation method according to the user and situation, such as when visual or auditory information presentation is more effective. The third concerns data acquisition. The only experimental participants in this experiment were university students. In order to verify the effects on users of different ages and experiences, it is necessary to conduct the experiment on a wide range of people. It is hoped that addressing these issues will refine the proposed method and lead to the development of a practical pedestrian navigation system.

6 CONCLUSION

This study investigates the effects of sequential information presentation in pedestrian navigation on users' spatial cognitive abilities, in particular their geospatial understanding, and on their mental workload of navigation. To achieve this objective, we proposed a method for sequentially presenting information on the surrounding area, even at points where no action decision is required, where information provision is limited in conventional navigation systems, and verified its effectiveness through experiments in a virtual urban environment.

The experimental results suggest that the proposed system is effective in improving users' spatial understanding and memory compared to conventional navigation. This result was supported by both the questionnaire, a subjective evaluation measure, and the path drawing and direction selection tasks, an objective evaluation measure. The sequential presentation of information is thought to promote spatial cognition by drawing the user's attention to the environment and facilitating the mapping between navigation information and subjective experience. Furthermore, the proposed system has been suggested to reduce user anxiety about navigation. This is thought to be a result of the sequential presentation of information, which encouraged users to actively seek information and actively participate in the navigation task. The sequential information presentation is an effective means of supporting users' spatial cognitive abilities and has the potential to make travelling in urban environments safer and more comfortable.

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