Model-Based Development of Spatial Movement Skill Training System and Its Evaluation

Ayumi YAMAZAKI†, Yuki HAYASHI†, Nonmembers, and Kazuisa SETA†, Senior Member

SUMMARY When moving through space, we have to consider the route to the destination and gather real-world information to check that we are following this route correctly. In this study, we define spatial movement skill as this ability to associate information like maps and memory with real-world objects like signs and buildings. Without adequate spatial movement skills, people are liable to experience difficulties such as going around in circles and getting lost. Alleviating this problem requires better spatial movement skills, but few studies have considered how this can be achieved or supported, and we have found no research into how the improvement of these skills can be supported in practice. Since spatial cognition is always necessary for spatial movement, our aim in this study is to develop a spatial movement skill training system. To this end, we first overviewed the use of knowledge gained from the research literature on spatial cognition. From these related studies, we systematically summarized issues and challenges related to spatial movement and the stages of spatial information processing, and created a new learning model for the improvement of spatial movement skills. Then, based on this model, we developed a system that uses position information to support the improvement of spatial movement skills. Initial experiments with this system confirmed that its use promotes recognition from a global viewpoint to the current location and direction, resulting in the formation of a cognitive map, which suggests that it has an effect on spatial movement skills.

key words: spatial movement skill, spatial cognition, cognitive map, cognitive map formulation

1. Introduction

When we move through space, we use various sorts of information as clues. This includes information acquired by examining the local surroundings, such as the scenery and road shape, and information that has been memorized by, for example, studying maps or from past experience. In recent years, it has also become possible to obtain position information in real-time from devices such as smartphones and tablet terminals. These days, it’s not unusual to see people with a GPS navigation tool in one hand, allowing them to check their position in order to get where they need to go.

However, people sometimes engage in exploratory activity with the aim of discovering things along the way, and may move differently for reasons of practicality (e.g., taking an unmapped short cut through a building) or in response to changing circumstances (e.g., considering the state of the road surface based on the local weather). In such cases, people are less likely to use navigation tools that assume the user will follow the displayed route. It has been shown that people who are using navigation devices have a smaller capacity for memorizing spatial elements, such as noticing short cuts and landmarks that they would naturally be aware of when not using these devices, and even change their gait characteristics relating to information gathering [1]. It has also been pointed out that these devices cause dilution of the direct interactions between humans and real spaces [2]. To move through space, it is essential to have an understanding of one’s current surroundings, which requires mental efforts such as estimating and confirming the current location [3]. When moving, people must also estimate and confirm their positional relationships and make efforts to guess the direction in which they are heading. Working out an optimal route to the destination requires the ability to identify a route by processing diverse information acquired through mental effort in an environment that changes as one moves through it. In this study, such abilities are defined as spatial movement skills. It is known that spatial movement skills can be used in spatial movement for any purpose [4].

Spatial movement skills exhibit individual differences, and research has been carried out in multiple fields with the aim of analyzing and clarifying individual differences and skill level trends. For instance, Wolbers and Hegarty discussed three types of interdependent domains, cognitive and perceptual factors, neural information processing and variability in brain microstructure, that have been related to navigational abilities from the perspective of perceptual and cognitive processing [5]. Moffat reviewed and discussed behavioral differences between older and younger adults in navigational skills in terms of the putative neural mechanisms [6]. Dabbs Jr et al. analyzed sex differences in navigation strategy and geographic knowledge [7]. Based on cognitive spatial tests, they found several differences, such as while men were better than women in mental rotation skills, men and women were similar in object location memory. On the other hand, as far as we investigated, we could not find any study that aimed at improving the spatial movement skill itself or verifying the effects of its improvement.

Ordinary navigation systems are designed to reduce the user’s cognitive load, making it unnecessary to estimate the route or seek confirmation. In practical use situations, users sometimes need to confirm the relationship between the physical objects around them (e.g., signs and buildings) and the displayed navigation map. While such interaction might be actually valuable to enhance users’ spatial movement skill, ordinary navigation systems are unfortunately

Copyright © 2020 The Institute of Electronics, Information and Communication Engineers
not essentially intended to train users for such extent. It follows that they cannot be regarded as learning tools that are suitable for improving the aforementioned skill. Therefore, in this study, we first present an overview of research related to spatial cognition and based on the existing findings and insights, we propose a learning activity model (spatial movement skill learning model). Then, we develop a model-based learning support system as a tablet terminal application and verify its effects on the improvement of spatial movement skill in comparison to an ordinary navigation system†.

2. Cognitive Map Formulation Process Based on Previous Studies

Spatial cognition is an essential skill for spatial movement. If people are unable to use spatial cognition to properly understand and recognize the space they are in, they will find it difficult to move to their destination. It thus appears that spatial movement skills are affected by spatial cognition skills for spatial awareness. In this study, based on our knowledge of spatial cognition research, we devise a learning activity aimed at improving spatial movement skills.

In spatial cognition research, a mental image representing the positional relationship between objects in the outside world is called a “cognitive map” [9]. This term is used across a wide range of disciplines in which spatial cognition research has been performed but is often used in a vague figurative sense to indicate something that performs the role of a map in the mind. In this study, we define a cognitive map as a mental representation relating to characteristics and constituent elements of an ordinary large-scale physical environment that is supported by internal concepts of short-term and long-term memory [10], [11].

As mentioned in Sect. 1, to the best of our knowledge, there is no study and learning support tool that aims to improve the spatial movement skill itself. In order to develop a learning activity model for improving spatial movement skills, in this section, we introduce the findings of research related to spatial cognition with an emphasis on the general concepts of cognitive map formulation process (Sect. 2.1), the cognitive map formulation method (Sect. 2.2), and information-gathering process and strategies in spatial movement (Sect. 2.3), respectively.

2.1 Cognitive Map Formulation Process

Cognitive maps are formed through activities such as moving around, observing physical maps, and asking people for directions. Wakabayashi summarized the cognitive map formulation process into six information processing stages as shown in Fig. 1: (1) contact with the environment, (2) encoding, (3) storage, (4) decoding, (5) replay/utilization, and (6) transformation [10]. The environment shown in Fig. 1 indicates a physical environment. Detailed description of each stage is provided in the following lines.

(1) Contact with the environment: this stage is divided into two modes. One is ‘direct experience’ which sustain the idea that people memorize information by direct contact with the environment through the sequence of observing scenes and physical kinesthetics when moving; the other one is ‘indirect experience’ which vehicle the idea that people acquire the information based on “visual or language media” such as reading physical maps and having a conversation with others.

(2) Encoding: this is the stage where the information in the short-term memory obtained in (1) is encoded. Here, the ‘procedural (route) knowledge’ about routes in traveled locations is mainly coded by direct experience, meanwhile ‘configurational (survey) knowledge’ about spatial relationships (see Sect. 2.2) is coded by indirect experience via physical maps.

(3) Storage: at this stage, the information encoded in (2) is stored in the long-term memory. The knowledge stored here is held in the form of ‘abstract or unconscious knowledge’ that is not necessarily in the form of linguistic expression.

(4) Decoding: this is the stage where the information stored in the long-term memory in (3) is retrieved, and decoded to the short-term memory (‘search/inference’ in Fig. 1). This stage corresponds to a psychological task called remembering.

(5) Replay/utilization: this stage deals with utilizing the decoded cognitive map information in (4), it is widely characterized with two behaviors: ‘spatial behavior’ through which people actually perform a spatial movement; and ‘transmission of spatial information’ through which people share with others navigation or map creation information.

(6) Transformation: at this stage, spatial behavior in (5) using the cognitive map causes contact with the physical environment again and brings new information, leading to the transformation of the cognitive map itself (right side of ‘transformation’ in Fig. 1). Besides, even without spatial behavior, spatial information transmission through media or conversation leads to the transformation of cognitive maps (left side of ‘transformation’ in Fig. 1).

In Fig. 1, processes regarding concepts that are related to the formulation of survey-type and route-type cognitive maps (see Sect. 2.2) are highlighted. These processes are taken into account as elements of the proposed learning model in Sect. 3.

2.2 Cognitive Map Formulation Method

In spatial cognition research, cognitive map representations that have been externalized from mental cognitive maps by free drawing can be classified into two types:
route maps, and survey maps [12]. Route maps, which are mainly formed by moving actions, are cognitive map representations formed by geospatial information obtained from moving actions. Although they have implicit qualities that come with physical activity and are not usually conscious, they constitute knowledge that is indispensable in route searching [10]. On the other hand, it is pointed out that survey maps are formed based on configurational (survey) knowledge. Montello defines configurational knowledge as “a map-like, or at least configurational, representation of metric spatial relationships between non-linearly-aligned sets of environmental features such as routes and landmarks” [13]. In other words, configurational knowledge is the knowledge that is necessary for facilitating route searches and developing new rules for including indirect relationships between points that are not directly connected [10], [11]. For instance, knowledge such as ‘landmark X and building Y face each other across the road’ or ‘building Z is two blocks away from the police station,’ are examples of configurational knowledge obtained by observing physical maps [14].

While there have been various theories regarding the order in which knowledge is acquired, today it widely accepted that the final stage of the development of cognitive maps is a survey map expressing configurational knowledge [10], [11]; people’s development stage of spatial information processing knowledge generally goes from route-type procedural knowledge to survey-type (higher-complexity) configurational knowledge.

On the basis of this theoretical background, we focus on learning activities that eventually increase the learner’s ability to formulate a survey-type cognitive map. To this extent, we assume that learners not only need to explicitly be conscious of exercising both route-type and survey-type knowledge in spatial planning and movement tasks but also they should reflect on both cognitive maps in order to internalize knowledge related to their spatial cognitive skills. A detailed learning model that reflects such learning activities is discussed in Sect. 3.

2.3 The Information-Gathering Process and Information Strategies Required for Spatial Movement

Wakabayashi demonstrated the concept of interaction in the processes of formulating and executing a plan of action in relation to when the information needed for spatial movement is acquired, and how it is acted upon (Fig. 2) [10]. When planning an action that involves movement, we must acquire information from sources such as external media and cognitive maps. When executing the plan, we need to associate the information contained in the plan with information acquired by direct observation of static landmarks along the way, such as buildings, signboards and road shapes, which are known to assist with route recognition and
location awareness [15]. It is also clear that the use of strategic knowledge when searching for a route to a destination results in accurate map learning [16]. It has been shown that one such strategy involves setting and satisfying “sub-goals” that are likely to be more feasible to solve the highest goal (final destination) [17].

Based on these findings regarding the information-gathering process and strategies in spatial movement, we consider learning activities that require learners to be explicitly conscious of static landmarks, sub-goals, these positional relationships, and directional relationships in the formulation of a movement action plan. Additionally, in the execution of the movement action plan, we consider learning activities dealing with learner’s ability to estimate the current location and the moving direction.

3. Development of a Spatial Movement Skill Learning Model

3.1 Spatial Movement Skill Learning Model

In the cognitive map formulation process discussed in Sect. 2.1, based on knowledge about the action plans discussed in Sect. 2.3 with regard to how information is acquired and how this information is used, we propose a learning activity model for improving spatial movement skills.

This spatial movement skill learning model is shown in Fig. 3. The rectangles correspond to the concepts in Fig. 1 that learners are required to explicitly carry out. Here, we take into consideration a cognitive internalization process after survey-type and route-type cognitive map formulation processes as a learning activity for enriching learners’ reflection. Our design guidelines are intended to support the following three learning activities:

1. Promote the formation of accurate survey-type cognitive maps from physical maps
2. Promote the formation of route-type cognitive maps by practicing spatial movements that establish correspondence between a survey-type cognitive map and the actual spatial environment
3. Integrate the images formed by activities 1 and 2 to promote the internalization of cognitive maps

3.2 Learning Flow

We propose learning activities and a learning flow based on the concept of interaction between action plans, information acquisition and orientation as shown in Fig. 2. Here, we take account of the reflection activity to promote the internalization of learners’ processes of formulating and executing an action plan mentioned in [10]. More concretely, learning support is provided in three phases: formulation of a movement action plan (planning), execution of the movement action plan (moving), and reflection on the formulating and executing processes (reflection).

**Phase 1 Planning:** In the first phase, the learner practices movement planning. Movement planning activities require learners to explicitly conduct map-reading from the physical map and devise a suitable path by gathering information about landmarks, sub-goals, positional relationships, and directional relationships.

**Phase 2 Moving:** In phase 2, learners practice moving in real space based on survey-type cognitive maps formed by movement planning in phase 1. The aim is to promote the formulation of cognitive maps by encouraging the learner to make a conscious effort to estimate the current location (current location estimation task) and the direction to the destination (direction estimation task), both of which are effective tools for cognitive map formation.

**Phase 3 Reflection:** The phase 3 is conducted just after finishing phase 2. In this phase, the learner reflects on the movement plan created in phase 1 and the movement activities performed by executing this plan in phase 2. By doing...
so, the system promotes internalization of the survey-type cognitive maps and route-type cognitive map formed at each stage.

4. Spatial Movement Skill Improvement Support System

We built a system to implement learning activities based on the spatial movement skill learning model proposed in Sect. 3.1. This system was implemented as an iOS application that can run on hand-held Apple iPad or iPhone devices. We used the Google Maps API as a source of map information, and we used a database (Realm) for learner authentication and learner data management.

Figure 4 shows the correspondence between the system’s interface and each phase of the learning flow described in Sect. 3.2. This consists of a Planning mode for movement planning activities in the first phase, a Moving mode for performing moving activities corresponding to the second phase task, and finally a Reflection mode for reflecting on the activities that were performed.

4.1 Planning Mode

In this mode, a physical map is used to perform movement planning activities aimed at creating an image of the environment from the map and formulating a movement action plan. To support this activity, the following three functions are provided.

1. Target point marker setting function: A function for setting sub-goals on the map in phase 2. Learners can set the sub-goals icon (red balloon marker in Fig. 4 (I-(i))) and their names by long-tapping at arbitrary points on the map.

2. Landmark marker setting function: A function for setting landmarks as indicators of movement on the map in phase 2. Learners can set the landmark icon (blue balloon marker in Fig. 4 (I-(i))) and their names by short tapping at arbitrary points on the map.

3. Moving route planning function: A route drawing function that learners can use when planning their own routes. The moving routes are drawn in blue lines following the order of learners’ tapping locations from the starting point icon (Fig. 4 (I-(ii))). In other words, learners draw their own route by thinking about at which sections they need to turn.

4.2 Moving Mode

In this mode, the learner moves in real space based on the movement action plan. The maps presented to the learner have different display content restrictions depending on the difficulty level set by the learner before moving. There are
three levels (easy, normal, hard), from the viewpoint of what kind of information can be used as a clue to understanding the current location:

(a) Easy level: requires a learner to understand the current location by accessing the direction information and the information about roads and the surroundings in addition to the learner’s set landmarks and sub-goals information.

(b) Normal level: the learner is expected to understand the current location by accessing the road information with the learner’s set landmarks and sub-goals information.

(c) Hard level: allows the learner to access just landmarks and sub-goals information set beforehand.

Corresponding to each level, the system displays a map with different restrictions placed on the added information, whereby the difficulty at each level is split into stages.

(A) Easy level: A map from which the icon showing the learner’s current location has been deleted (Fig. 4 II(i)-(A))

(B) Normal level: A map from which all the items (e.g., buildings and text information) except for markers set by the learner have been deleted (Fig. 4 II(i)-(B))

(C) Hard level: A map that displays no information apart from a destination marker and landmark markers (Fig. 4 II(i)-(C))

In order to move towards a destination, the learner must be aware of where he or she is. To make learners consciously aware of this, we set up a function to implement and record a current location estimation task to promote awareness of the present location (yellow balloon marker in Fig. 4 II(ii)). Also, since estimating the direction of the destination from the current location is useful for forming a survey map, the system also includes functions for implementing and recording the direction estimation task by allowing learners to select one of the displayed eight directions record button, as shown in Fig. 4 II(ii). Learners can perform these estimation tasks at any time when they use the moving mode.

A record of these two types of estimation tasks is stored together with the actual correct answers to facilitate reflection. For the same reason, we also installed a GPS logger to record information on the actual route traveled.

4.3 Reflection Mode

This mode is used after practicing moving in real space (i.e., moving mode). In this mode, the cognitive map formed through the Planning and Moving modes is externalized, and the learner reviews the results of estimating the current location and direction, which are considered to contribute to cognitive map formulation during learning.

More concretely, the learner performs reflection relying on his or her own memories and thoughts while traveling by using free drawing to externalize the survey-type cognitive map in the form of a sketch map. The route map is also externalized by freely drawing the traveled route on a displayed map. Figure 4 (III-(i)) represents the interface of the reflection task. Here, a picture of the learner’s sketched map can be uploaded to the system for comparing the sketched map to the physical map (i.e., Google map information). Also, the learner can draw the route by reflecting on the traveled itinerary memories using the route (blue lines) drawing function as explained in Sect. 4.1 (3). Then, the system displays the moving route planned on planning mode (red lines) and the actual moving route based on GPS record information (gray lines).

In addition, by comparing the externalized cognitive map data with data such as location and direction estimations made while moving and their correctness, the learner can reflect on whether his or her awareness was effective during the moving task. Figure 4 (III-(ii)) shows the system interface during the reflection mode. The learner can grasp the results of the comparison between estimated location/direction and the corresponding actual location/direction. To enable movement actions that were performed once by the user to be reviewed again at a later time, details of the reflection are recorded and stored.

5. Experimental Studies (Experiment 1)

We performed initial experiments to get a feel for how the use of the spatial movement skill improvement support system described in the previous section contributes to the improvement of spatial cognition.

5.1 Experimental Setting

5.1.1 Test Subjects and Experimental Tasks

This experiment was performed with the cooperation of six undergraduate students and six graduate students. Before conducting the experiment, we asked the test subjects to complete a questionnaire about their sense of direction proposed in [18]. Based on these results, the test subjects were divided into two groups with no significant difference in score ($t(10) = 0.02, p = 0.98$). One group of six people used the system we developed (G1: 4 males, 2 females), and the other group of six people used a GPS navigation app (G2: 4 males, 2 females).

Based on a preliminary investigation, we decided to perform the experiment in the vicinity of Kitanoda station in Sakai city in Osaka Prefecture, Japan, which none of the test subjects had visited before.

Starting from Kitanoda Station, both groups of test subjects were instructed to find their way to a destination point just under one kilometer away. During this movement, they were also set tasks that required them to travel via three preset points (buildings) in a specific order. To facilitate these tasks, the subjects in both groups were shown maps of the waypoints and their final destination.
5.1.2 Experimental Procedure

The experimental procedure is shown in Table 1. We designed and scheduled the experiments in a way that each test subject went through the whole experimental procedure alone at different times.

First, we described the places where both groups would be moving (P1). We then used the system’s planning mode function to devise a movement plan for G1 (P2). Next, we instructed both groups to remain aware of their estimated current location and the direction of the destination (P3).

After reaching the location of the test, G1 moved by using the system’s Moving mode (P4-S). Regarding the efforts of the test subjects to solve the movement tasks using their estimated current location and the estimated direction of the destination, we decided in this test to make the tasks optional for reasons of safety, and we avoided interruptions from the system and minimized the number of responses (P4-N). G2, on the other hand, was asked to move while according to the spoke directions provided by the GPS navigation app. Just like when using ordinary navigation tools, they were allowed to check the map screen.

After reaching the destination, both groups completed a questionnaire as shown in Table 2 (P5) and performed drawing activities in which they drew maps of the surroundings of the movement tasks (P6), and of the route they traveled on a map (P7). After that, G1 used Reflection mode to perform a reflection activity in which they were asked to complete questionnaire 1 again (P8). Finally, both groups completed questionnaire 2 as shown in Table 3 (P9).

Note that we asked subjects who completed the experiment not to reveal anything about the experimental contents to other participants.

5.2 Experimental Results

5.2.1 Results of Questionnaires

In questionnaire 1 conducted after moving, there was no significant difference between the groups in terms of the number of responses to each question (Table 2).

When G1 completed the questionnaire again while using the Reflection mode function, we noticed a change in their self-awareness.

In questionnaire 2 (Table 3), which both groups were
asked to complete at the end of the experiment, the test subjects rated their experiences on a 5-point scale (1: negative, 2: somewhat negative, 3: neither positive nor negative, 4: somewhat positive, 5: positive). We investigated the equality of variance using F-test. The result showed that the two groups’ scores can be regarded as having equal variance for each question. Out of the nine questions, a t-test assuming equal variance showed significant differences in Q3 \((t(10) = -3.16, p < .05)\) and Q7 \((t(10) = 2.90, p < .05)\).

5.2.2 Analysis of Cognitive Maps Based on Sketch Maps

As our method for the analysis of sketch maps produced by externalizing cognitive maps, we classified them into survey maps and route maps based on a closed-loop method used for the analysis of hand-drawn maps [19].

The closed-loop method classifies sketch maps according to whether or not they contain a closed road network. In this method, if there is a closed region in the sketch map, then it is considered that the space is depicted as having breadth, so the map is classified as a survey type map. Conversely, if there is no closed area, then the map is classified as a route-type map which treats space in a linear fashion. Figure 5 shows some examples of sketch maps and movement route maps drawn by test subjects, and the classifications of these maps. The left side of Table 4 represents classified sketch maps into survey maps and route maps based on a closed-loop method. There was no significant difference between the groups in terms of the number of the maps classified.

Furthermore, we analyzed how much the sketch maps resembled survey maps with reference to the buffer method [19].

In analysis by the buffer method, when using GIS to analyze a sketch map, errors and distortion in the drawing must be objectively fitted to the actual topography, so the sketch map has to be transformed into an actual map. This transformation was performed by two third-party assistants with no knowledge of the sketch map evaluation method.

Figure 6 shows the changes in the rate of increase in the area of the buffered regions. In each interval of buffer distance at 10 m, we confirmed that two groups’ scores can be

| Q1 | I remember the scenery I saw while moving | 4.33 | 4.00 |
| Q2 | I remember what I was thinking while moving | 4.33 | 4.17 |
| Q3 | I was conscious of my current location while moving | 4.00 | 4.67 |
| Q4 | I was aware of which direction I was headed while moving | 3.83 | 4.33 |
| Q5 | I considered the positional relationship between my current location and the destination | 3.83 | 4.50 |
| Q6 | I considered the direction relationship between my current location and the destination | 3.50 | 4.00 |
| Q7 | Drawing a local map helped me understand my positional relationship with the surroundings | 4.50 | 3.17 |
| Q8 | Drawing the movement route helped me understand my positional relationship with the surroundings | 4.33 | 3.50 |
| Q9 | When reflecting on my movements, I found it easy to remember what I had memorized while moving | 3.83 | 3.83 |

Table 3  Questionnaire 2 contents and average response rates.

| Type                  | Average number of landmarks |
|-----------------------|-----------------------------|
| G1 (n=6)              | Survey map: 4, Route map: 2 | 7.33 |
| G2 (n=6)              | Survey map: 4, Route map: 2 | 1.67 |

Table 4  Sketch map classification results (Exp. 1).
regarded as having equal variance based on F-test. A t-test with a significance level of 5% and buffer distance at 10 m intervals assuming equal variance showed a significant difference when the buffer distance exceeded 50 m. As shown in Fig. 6, the rate of increase in the area of the buffered regions tended to become smaller in G1 as the buffer distance increased, showing that G1 had a greater tendency to produce survey maps.

The right side of Table 4 shows the average number of landmarks in maps produced by G1 and G2. The results of a t-test confirmed that there was a significant difference between the two groups (t(10) = 4.05, p < .01). These results show that G1 memorized more information.

5.3 Discussion

The lack of significant differences between the groups in questionnaire 1 may have arisen because both groups were provided with instructions before starting to move, making them aware of how to estimate their current location and the direction from there to the target destination. When using the Reflection mode and completing questionnaire 1 again while comparing the learners’ record with the correct answers, it seems that some items changed because of a memory replay effect caused by the display of the actual route. When we asked why they had changed their answers after the experiment, we received comments such as “I changed my mind because when doing the actual movements, I remembered what I had memorized, which was easy to recall”. This suggests that we achieved our purpose of promoting reflection with a user interface that made it possible to compare screens implemented in Reflection mode.

In Q3 of questionnaire 2, significant differences and significant tendencies indicated that the group using the navigation system was more aware. This is thought to be partly due to the inclusion of spoken navigation. The spoken navigation instructions include information about the latest movement actions, such as “In 30 meters, turn to the west.” To follow these instructions, the learners must be aware of the relative positional relationship between their current position and the action point, and it seems that the local awareness needed for this was promoted more than in group G1.

On the other hand, the analysis results of the sketch map for the cognitive map formed as a result of the movement suggest that G1 is more advanced. This also supports the above interpretation that navigation systems promote local awareness. It is thus suggested that our system is more suitable than a GPS navigation app as a learning environment that makes people more aware of distances and directions from a more global viewpoint that is needed for cognitive map development. The significant positive difference in the responses of G1 to Q7 of questionnaire 2 could be due to a difference in the information content of the cognitive maps formulated by the two groups. As mentioned in Sect. 1, people tend to memorize less peripheral information when using navigation systems. We also confirmed a significant difference in the number of landmarks drawn in this study. One possible reason for this is that the results of experiencing the effects of better memory organization are reflected due to there being a greater amount of memories in G1 in the externalization of survey maps and route maps that form part of the reflection activity aimed at organizing memories.

It is thus concluded that by putting together the spatial cognition improvement effects of using our spatial movement skill improvement support system, the group using the navigation system were more aware of their current location and orientation for the selection of local actions, but from the representation of sketch maps such as the density of information and the number of landmarks, G1 were more aware of their current location and orientation from a global viewpoint, and formed more advanced cognitive maps as a result. This suggests that our system can contribute to the formation of spatial cognitive maps, and that it is possible to improve spatial movement skills by continuing to tackle spatial movement tasks using this system.

6. Additional Experimental Studies (Experiment 2)

We conducted additional experiments about one month after finishing Experiment 1 to confirm that the results in the previous section are not due to differences in the original spatial movement abilities of the test subjects but rather the effect of using the system.

6.1 Experimental Setting

Additional experiment was performed with the cooperation of 12 test subjects from Experiment 1 and four undergraduates as new collaborators. In the experiment, the group was composed of 12 subjects of Experiment 1 as the system use group (G3: 8 males, 4 females) and four newly cooperated with the GPS navigation app use group (G4: 3 males, 1 female). As in experiment 1, there was no significant difference between the two groups (t(14) = 0.00, p = 1.00) on the direction sense scores [18].

The experiment was conducted by the same instruction and procedure as in the experiment 1 (Table 1). As the first place to visit for all subjects, we perform the experiment in the vicinity of Asakayama station in Sakai city in Osaka Prefecture, Japan. Following the experiment 1, starting from Asakayama Station, both groups of test subjects were instructed to find their way to a destination point just under one kilometer away. Also, the route presented by the GPS navigation application set three preset points (buildings) as in experiment 1. Note that each of the process was conducted individually by each participant at different times.

Through the additional experiment, we confirm 2 things: (1) whether the same difference as in experiment 1 would be shown for understanding of space in another subject and another place by comparing G3 and G4, and (2) whether the significant difference of experiment 1 is due to the difference of original spatial movement abilities of test subjects or effect of using the system by confirming the sig-
6.2 Experimental Results

6.2.1 Results of Questionnaires

Table 5 shows a result of questionnaire 1. G3 completed the questionnaire again while using the Reflection mode function as in experiment 1. In some of the items, we noticed a change in their self-awareness.

In questionnaire 2, which contents are shown in Table 6, we confirmed that two groups’ scores can be regarded as having equal variance in each question based on F-test. Then, a t-test assuming equal variance showed no significant differences in all items.

6.2.2 Analysis of Cognitive Maps Based on Sketch Maps

The left side of Table 7 represents classified sketch maps into survey maps and route maps based on a closed-loop method. It shows G3 had a greater tendency to produce survey maps. The right side of Table 7 shows the average number of landmarks in maps produced by G3 and G4. The results of a t-test confirmed that there was marginally different between the two groups (t(14) = 2.14, p < .10). These results show that system usage group (G3) memorized more information, i.e., the same trend was shown as experiment 1.

Figure 7 shows the changes in the rate of increase in the area of the buffered regions. As in experiment 1, F-test results showed that two groups’ scores can be regarded as having equal variance in each interval of buffer distance at 10 m. A t-test with a significance level of 5% and buffer distance at 10 m intervals assuming equal variance showed a significant difference when the buffer distance exceeded 70 m. As shown in Fig. 7, the rate of increase in the area of the buffered regions tended to become smaller in G3 as the buffer distance increased, showing that G3 had a greater tendency to produce survey maps as well as experiment 1.

Furthermore, there was no significant difference between experiment 1’s system usage group (G1) and the navigation use group (G2) as shown in Fig. 8.

6.3 Discussion

The results in experiment 2 suggested that the use of the system provides positive influences for the proper spatial understanding, since same tendency in experiment 1 is shown.
about survey map trend of sketch maps and average number of landmarks, and no significant difference between experiment 1’s test subjects using the system (G1) and navigation system (G2) is confirmed in this time.

Consequently, it is suggested that the result of experiment 1 is not due to the difference in the original spatial movement ability of the test subject but due to using the system.

7. Conclusion

In this study, we developed a support system for improving spatial movement skills based on a model that we built based on integrating knowledge about spatial cognition research, and we verified the effects of this system. This system is based on a learning model that builds on our knowledge of spatial cognition research based on the idea that spatial movement skills influence spatial movement ability.

In an initial evaluation experiment conducted with undergraduate and postgraduate university students, we confirmed that it was better than a navigation app at supporting their spatial cognition. Based on the results of questionnaires, we also found that the Reflection mode has a positive effect on spatial understanding, which suggests it has an effect on spatial cognition.

We acknowledge that further experiments are needed to confirm actual improvement of spatial movement skills since the relatively small number of test subjects at this stage can be viewed as a limitation of this study. Hence, in the future, we plan to carry out long-term evaluations by increasing the number of subjects to collect more reliable data and verify whether the learning effects persist even in the long term.

It is also necessary to verify how much spatial cognitive skill contributes to improvement of spatial movement skill. Furthermore, we aim to develop a more suitable system to support the improvement of spatial movement skills through methods such as intervention in direct learning by conducting an investigation based on opinions gained from experimental collaborators.

Acknowledgments

We would like to express our gratitude to everyone who took part in this study’s experiments.

References

[1] N. Ishii and K. Nishiuchi, “A Cognitive Experiment on Influence of Walk Navigation during Wayfinding on Spatial Memory,” Infrastructure Planning Review, vol.21, pp.425–434, 2004. (in Japanese)

[2] H. Hirai and S. Mori, “Relation between use of the GPS navigation tool and the action in way-finding: a study on act-finding in urban space,” Journal of the City Planning Institute of Japan, vol.42, no.3, pp.541–546, 2007. (in Japanese)

[3] E. Lindberg and T. Gärling, “Acquisition of different types of locational information in cognitive maps: Automatic or effortful processing?,” Psychological Research, vol.45, no.1, pp.19–38, 1983.

[4] R. Passini, “Spatial representations, a wayfinding perspective,” Journal of Environmental Psychology, vol.4, no.2, pp.153–164, 1984.

[5] T. Wolbers and M. Hegarty, “What determines our navigational abilities?,” Trends in cognitive sciences, vol.14, no.3, pp.138–146, 2010.

[6] S.D. Moffat, “Aging and spatial navigation: what do we know and where do we go?,” Neuropsychology review, vol.19, no.4, pp.478–489, 2009.

[7] J.M. Dabbs Jr, E.-L. Chang, R.A. Strong, and R. Milan, “Spatial ability, navigation strategy, and geographic knowledge among men and women,” Evolution and human behavior, vol.19, no.2, pp.89–98, 1998.

[8] A. Yamasaki, Y. Hayashi, and K. Seta, “Enhancing spatial cognition skills based on cognitive map formulation processes,” Proc. 26th International Conference on Computers in Education (ICCE), pp.377–386, 2018.

[9] E.C. Tolman, “Cognitive maps in rats and men,” Psychological review, vol.55, no.4, pp.189–208, 1948.

[10] Y. Wakabayashi, “Spatial analysis of cognitive maps,” Chijin-shobo, 1999. (in Japanese)

[11] Y. Wakabayashi, “Spatial analysis of cognitive maps,” Geographical Reports of Tokyo Metropolitan University, vol.29, pp.57–102, 1994.

[12] F.N. Shemaykin, “General problems of orientation in space and space representations,” Psychological Science in the USSR. Arlington, VA: US Office of technical Reports, 1, 1962.

[13] D.R. Montello, “A new framework for understanding the acquisition of spatial knowledge in large-scale environments,” Spatial and temporal reasoning in geographic information systems, pp.143–154, 1998.

[14] T.P. McDonald and J.W. Pellegrino, “Psychological perspectives on spatial cognition,” T. Gärling & R.G. Golledge (Eds.), Behavior and Environment, pp.47–82, Amsterdam: Elsevier Science Publishers, 1993.

[15] K. Clayton and M. Woodyard, “The acquisition and utilization of spatial knowledge,” Cognition, social behavior, and the environment, pp.151–161, 1981.

[16] A.K. Lobben, “Tasks, strategies, and cognitive processes associated with navigational map reading: A review perspective,” The Professional Geographer, vol.56, no.2, pp.270–281, 2004.

[17] M. Hietro, H. Hara, and T. Monnai, “Wayfinding in urban space as a problem solving concerning lostness and finding,” Journal of Architecture, Planning and Environmental Engineering, vol.59, no.466, pp.65–74, 1994. (in Japanese)

[18] Y. Takeuchi, “Sense of direction and its relationship with geographical orientation, personality traits and mental ability,” Japanese Journal of Educational Psychology, vol.40, no.1, pp.47–53, 1992. (in Japanese)

[19] K. Okamoto, K.I. Okunuki, and T. Takai, “Sketch map analysis using GIS buffer operation,” Proc. International Conference on Spatial Cognition, pp.227–244, Springer, Berlin, Heidelberg, 2005.
Yuki Hayashi received his Ph.D. in Information Science from Nagoya University in 2012. From 2009 to 2012, he was a recipient of the JSPS research fellowship for young scientists (DC1). From 2012 to 2014, he was an assistant professor at Seikei University. He is currently an associate professor in the College of Sustainable System Sciences and the Graduate School of Humanities and Sustainable System Sciences, Osaka Prefecture University. His research interests include computer-supported collaborative learning and human-computer interaction. He received JSAI SIG-Awards in 2015 and 2017, a JSiSE SIG-Award in 2017, the ICCE Best Overall Paper Award in 2017, and the JSAI 30th Anniversary Best Paper Award in 2016. He is a member of IPSJ, JSAI, JSiSE, HIS, APSCE, and ACM.

Kazuhisa Seta received a Ph.D. from Osaka University in 1998. He is currently a professor in the Graduate School of Humanities and Sustainable System Sciences, Osaka Prefecture University. His research interests include software engineering, intelligent tutoring systems, human computer interaction, semantic web and ontological engineering. He received SIG-Awards from Japanese Society of Artificial Intelligence in 2015 and 2017, SIG-Award from Japanese Society for Information and Systems in Education 2017, Best Overall Paper Award from ICCE in 2017 and Best Paper Awards from the Japanese Society for Information and Systems in Education in 2012 and 2015, respectively. He is a member of IEICE, JSAI, IPSJ, JSiSE, JCSS, APSCE, ACM and IAIED.