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Enhancing Spatial Cognition Skills Based on Cognitive Map Formulation Processes

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Abstract: When moving through a 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 support the improvement of spatial movement skills through the use of knowledge gained from the research of spatial cognition. From these related studies, we systematically summarized the knowledge of problems in spatial movement and the stages of spatial information processing, and we created a new learning model for the improvement of spatial movement skills. 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.

Keywords: 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.

But 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 (Ishii & Nishiuchi, 2004). It has also been pointed out that these devices cause dilution of the direct interactions between humans and real spaces (Hirai & Mori, 2007).

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 (Lindberg & Gärling, 1983). 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

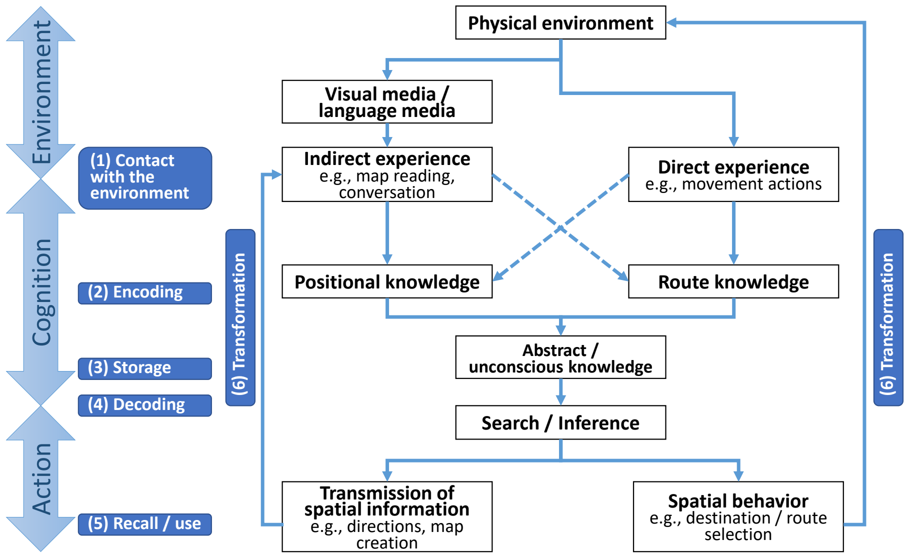

Figure 1. Concept of Cognitive Map Formulation as an Information Processing Procedure (created by the authors based on (Wakabayashi, 1999; Wakabayashi, 1994))

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 (Passini, 1984).

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. On the other hand, no research has been done with the aim of improving this ability or verifying the effects of improvement. Ordinary navigation systems are considered to be unsuitable as tools for improving spatial movement skills because they overload the user with information and make it unnecessary for the user to estimate the route or seek confirmation. As a result, they cannot be regarded as learning tools that are suitable for improving skills. Therefore, in this study, we present an overview of research into spatial cognition and we propose a learning activity model (spatial movement skill learning model) based on the findings of this research. We also develop a model-based learning support tool as tablet terminal application and verify its effects on the learning of spatial movement skills.

2. Cognitive Map Formulation Process Based on Previous Studies

Spatial cognition is an essential skill for spatial movement. If a person is 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” (Tolman, 1948). 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 (Wakabayashi, 1999; Wakabayashi, 1994).

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 formation process into six

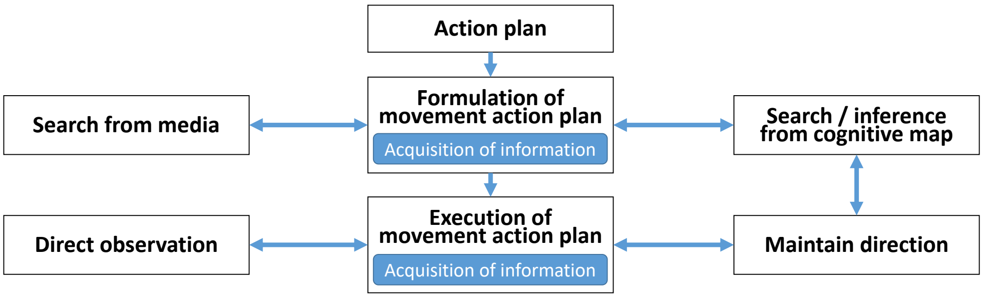

Figure 2. Concept of Interaction between Action Plans, Information Acquisition and Orientation (created based on (Wakabayashi, 1999))

information processing stages as shown in Figure 1 (Wakabayashi, 1999; Wakabayashi, 1994): (1) contact with the environment, (2) encoding, (3) storage, (4) decoding, (5) recall and utilization, and (6) transformation. The environment shown in Fig. 1 indicates a physical environment. At the stages of cognition, (1) contact with the environment includes both direct and indirect contact, and although these result in the formation of different kinds of knowledge, the results are encoded at stage (2) and stored as abstract or unconscious knowledge at stage (3) At the action stage, the stored cognitive map is (5) recalled and used. By using the map at stage (5), the cognitive map is transformed at stage (6) through the acquisition of new information by coming into contact with the environment again.

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 (Shemaykin, 1962). 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 (Wakabayashi, 1999). On the other hand, survey maps are formed by positional knowledge, which is information obtained by observing physical maps (McDonald & Pellegrino, 1993). Positional knowledge is knowledge that is necessary for facilitating route searches and developing new rules and includes indirect relationships between points that cannot move directly (Wakabayashi, 1999; Wakabayashi, 1994).

There are various theories of the order in which knowledge is acquired, but today it is generally thought that the final stage of the development of cognitive maps is a survey map expressing positional knowledge (Wakabayashi, 1999; Wakabayashi, 1994). Therefore, in this study, as a factor that contributes to the improvement of spatial movement skills, we consider learning activities that increase the ability to formulate a cognitive map like a survey map.

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) (Wakabayashi, 1999). 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 (Clayton & Woodyard, 1981).

It is also clear that the use of strategic knowledge when searching for a route to a destination results in accurate map learning (Lobben, 2004). It has been shown that one such strategy involves setting and satisfying sub-goals that are less difficult (Hiiro et al., 1994).

3. Development of a Spatial Movement Skill Learning Model and a Support System Based on This Model

3.1 Spatial Movement Skill Learning Model

In the cognitive map formulation process discussed in Section 2.1, based on knowledge about the action plans discussed in Section 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. In this study, our design guidelines are 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

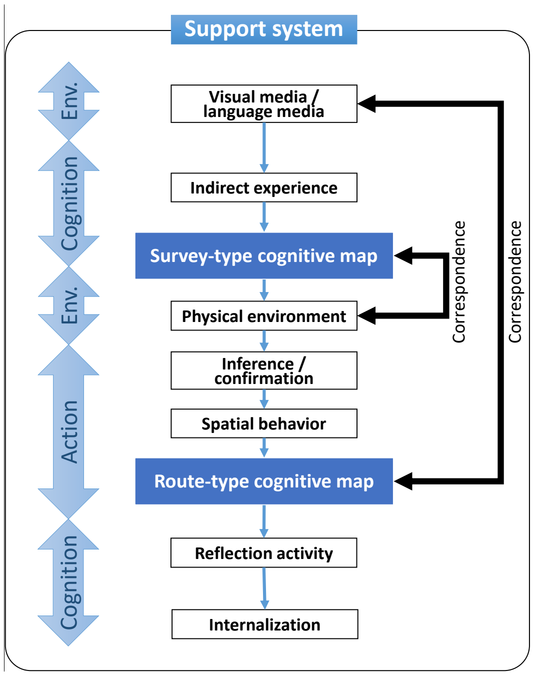

Figure 3. Spatial Movement Skill Learning

3.2 Learning Flow

Here we propose learning activities and a learning flow based on the learning guidelines proposed in the previous section. Based on the information-gathering process required for spatial movement (Fig. 3), learning support is provided in three phases: planning movements (planning), putting these movement plans into action (moving), and reflecting on the outcome (reflection).

Phase 1: Planning: In the first phase, the learner practices movement planning. Movement planning activities provide learners with the opportunity to explicitly demonstrate their map-reading skills and their ability to devise a suitable path by gathering information about landmarks, 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: In phase 3, the learner reviews 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.

3.3 Spatial Movement Skill Improvement Support System

We built a system to implement learning activities based on the spatial movement skill learning model proposed in Section 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

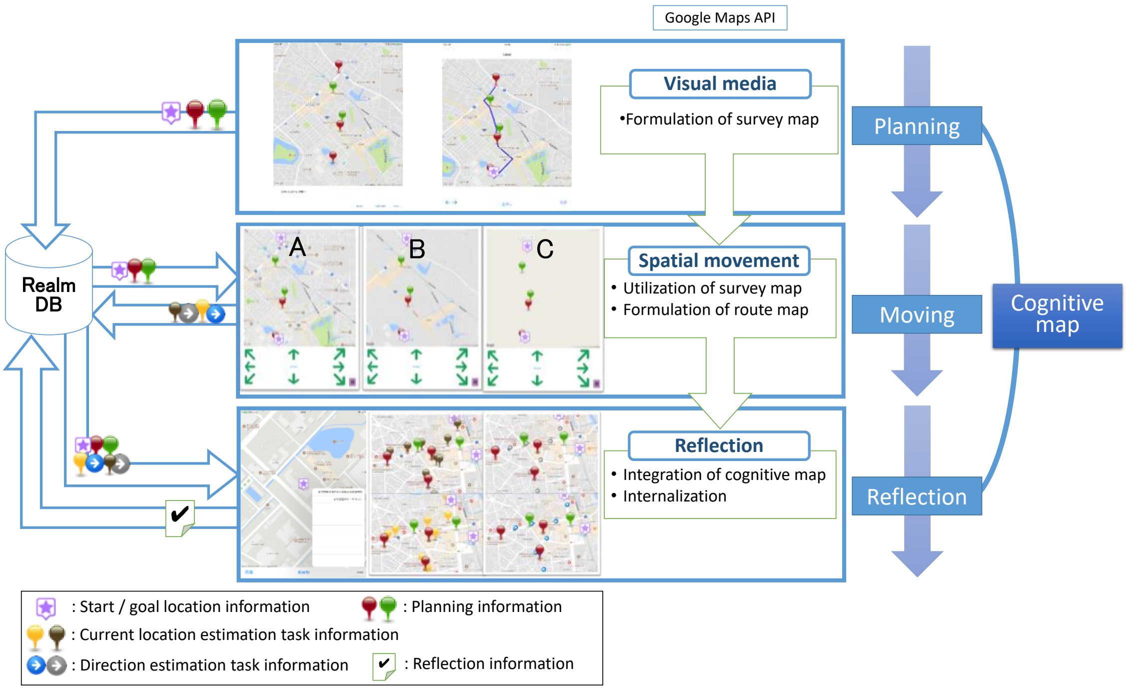

Figure 4. Learning Flow and System Diagram

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 Section 2.5. 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.

3.4 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 in Fig. 4 and formulating a movement action plan in Fig. 3. 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
(2) Landmark marker setting function: A function for setting landmarks as indicators of movement on the map in phase 2
(3) Moving route planning function: A route drawing function that people can use when planning their own routes

3.5 Moving Mode

In this mode, the learner moves in real space based on movement plan. The maps presented to the learner have different display content restrictions depending on the level set by the learner before moving. There are three different levels, in which the learning objectives are set as follows:

(a) Use the direction of travel and information about roads and the surroundings to understand the current location
(b) Use landmarks and roads to understand the current location
(c) Move using marks and their positional relationships

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

(A) A map from which the icon showing the learner's current location icon has been deleted
(B) A map from which all the items (e.g., buildings and text information) except for markers set by the learner have been deleted
(C) A map that displays no information apart from a destination marker and landmark markers

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 fact, we set up a function to implement and record a current location estimation task to promote awareness of the present location. Also, since estimating the direction of the destination from the current location is useful for forming a survey map, it also includes functions for implementing and recording the direction estimation task.

A record of the estimation task is stored together with the actual correct answer to facilitate reflection on the learner's guessing skills when reviewing. For the same reason, we also installed a GPS logger to record information on the actual route traveled.

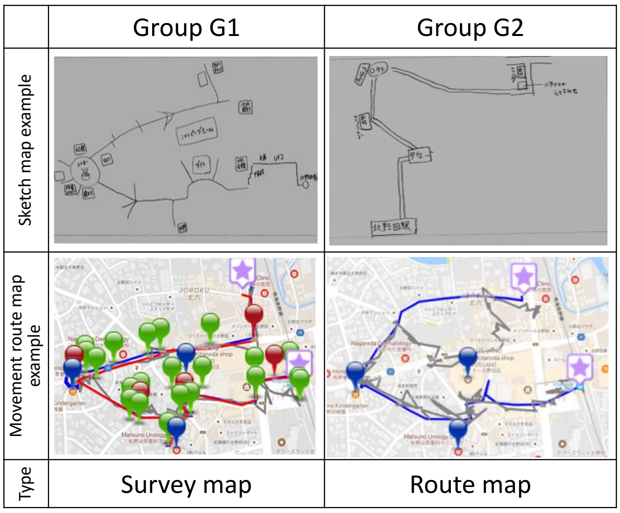

Figure 5. Results of Local Map and Movement Route Drawing Tasks

3.6 *Reflection Mode*

In this mode, the cognitive map formed through the Planning and Moving modes is externalized, and the learner reviews the results of inferring the current location and direction (which are considered to contribute to cognitive map formulation during learning).

The learner reflects 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.

By comparing the externalized cognitive map data with the data such as guesses made while moving and the correctness of these guesses, the learner reflects on whether or not his or her awareness was effective during this spatial movement task. To enable movement actions that were performed once by the user to be reviewed again at a later date, the details of the reflection are remembered.

4. Experimental Studies

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 improvement of spatial cognition.

4.1 *Experimental Setup*

4.1.1 *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 had the test subjects complete a questionnaire based on a set of questions about their sense of direction (Takeuchi, 1992), and we scored the students according to their self-evaluated sense of direction. Based on these results, the test subjects were divided into two groups with no significant difference in score. 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.

Table 1

Experimental Procedure

	Group G1	Group G2
P1	Description of the experiment location	
P2	Movement planning activity (Planning)	–
P3	Instructions Estimate one's own current location Estimate the direction to the destination as seen from the current location	
P4	P4-S: Movement activity (Moving) Current location estimation task Direction estimation task	P4-N: Navigation Move according to spoken instructions
P5	Questionnaire 1 (Table 2)	
P6	Sketch map drawing	
P7	Movement route drawing	
P8	Reflection activity (Reflection) Repeat questionnaire 1 (Table 2)	–
P9	Questionnaire 2 (Table 3)	

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.

4.1.2 Experimental procedure

The experimental procedure is shown in Table 1. 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 group 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, group 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). Group 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 (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, group 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 (P9) (Table 3).

4.2 Experimental Results

4.2.1 Questionnaire 1

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

4.2.2 Questionnaire 2

In questionnaire 2, 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

Table 2

Questionnaire 1 Contents and Average Response Rates

	Were you aware of the following?	Average number of people		
		G1		G2
		Before	After	
Q1	Using positional relationships on the map seen at the Planning stage	6	6	4
Q2	Using directional relationships on the map seen at the Planning stage	3	3	3
Q3	Thinking about where you were on the map	6	4	5
Q4	Memorizing landmarks when changing direction	1	1	2
Q5	Remembering what was memorized at the Planning stage	4	4	2
Q6	Thinking about in which direction the destination is located	3	6	6
Q7	Confirming the direction to the destination based on positional relationships	4	5	5
Q8	Memorizing landmarks	3	3	2

Table 3

Questionnaire 2 Contents and Average Response Scores

	Question content	Average score	
		G1	G2
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

positive nor negative, 4: somewhat positive, 5: positive). Out of the nine questions, a t-test assuming equal variance showed significant differences in Q3 ($t(10)=-3.16$, $p<.05$) and Q7 ($t(10)=2.90$, $p<.05$).

4.2.3 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 (Okamoto et al., 2004).

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. Furthermore, we analyzed how much the sketch maps resembled survey maps with reference to the buffer method (Okamoto et al., 2004).

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. A t-test with a significance level of 5% and buffer distances 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 group G1 as the buffer distance increased, showing that group 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 group G1 and group G2. The results of a t-test confirmed that there was a significant difference between the two groups ($t(10)=4.052$, $p<.01$). These results show that group G1 memorized more information.

Table 4 *Sketch Map Classification Results*

	Type		Average number of landmarks
	Survey map	Route map	
Group G1	4	2	7.33
Group G2	4	2	1.67

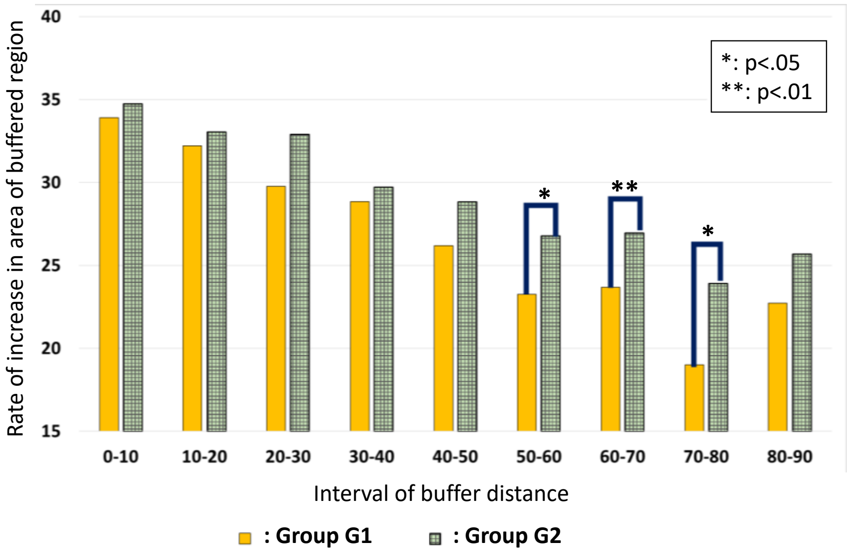

Figure 6. The Tendency of Sketch Maps to Resemble Survey Maps

4.3 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 group 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 group 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 Section 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 group 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, group 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.

5. Conclusion

In this study, we developed a support system for improving spatial movement skills based on 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.

Further work is needed to verify the improvement of spatial cognition skills in long-term use. 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.

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