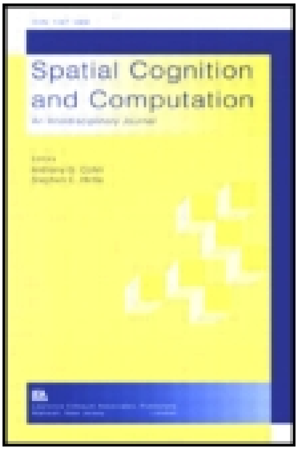

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Development of Landmark Knowledge at Decision Points

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Development of Landmark Knowledge at Decision Points

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Abstract: Two experiments investigated how people develop different landmark knowledge at decision points. Participants learned a route in a virtual city once or five times. One distinctive landmark was placed at each intersection of the route. At test, participants were released at each intersection according to the learning order and were required to determine the turning direction. At each intersection, the landmark was removed (no landmark), correctly placed (one landmark), duplicated on the other side (two identical landmarks), or misplaced from another intersection (two different landmarks) to disrupt the landmark sequence. The results suggested that humans develop different landmark knowledge (landmark knowledge for guidance, landmark knowledge for place recognition and knowledge of landmark sequence) with different navigation experience.

Keywords: landmark, large-scale environment, spatial cognition, spatial microgenesis

1. INTRODUCTION

Following a route (e.g., a route from home to office) is one of the most common behaviors in humans' daily life. Efficient route following behavior requires making correct turns at decision points where heading change might occur. Research has demonstrated that landmarks at decision points are important in route following behavior. People frequently use landmark as references when they plan and describe routes (Denis, 1997; Denis et al., 1999; Holscher et al., 2011; Tom and Denis, 2004). With the presence of landmarks, people need fewer learning trials to learn a route (Jansen-Osmann, 2002). Poorer performances in recognizing, recalling, and ordering landmarks are highly related to impaired wayfinding behavior for older people (Head & Isom, 2010;

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Wiener et al., 2012) and schizophrenic patients (Daniel et al., 2007). People also remembered the landmarks at decision points better than landmarks at nondecision points (Janzen & Jansen, 2010; Janzen & van Turennout, 2004).

The facilitation of landmarks in route following might occur because people use landmarks (a) to determine their locations and orientation in a route, (b) to choose their moving directions at decision points, (c) to anticipate the subsequent segments of the route (e.g. Mallot & Gillner, 2000; Ruddle et al., 2011; Siegel & White, 1975; Thorndyke & Hayes-Roth, 1982; Tolman et al., 1946; Waller & Lippa, 2007). In the current study, we focused on the landmark function in direction selection at decision points when people follow a route.

Waller and Lippa (2007) demonstrated that people are able to use landmarks as beacons or associative cues to choose turning directions at decision points. In their experiments, participants learned to pick one of two doors at each decision point. For half of the participants, a landmark was placed on the same side of the correct door so that participants would use the landmark as a beacon. For the other half of the participants, a landmark was placed in the middle of the two doors so that participants needed to associate the relative location of the correct door with a specific landmark (e.g., picking the right door at landmark A). The results showed that both groups of participants could learn the correct route although the group in the beacon cue condition learned faster than the group in the associative cue condition.

Mallot and Gillner (2000) proposed that people might associate directional choice with views at each decision point. In their study, participants learned a route consisting of several Y-shaped junctions and each junction consisted of three landmarks which were in front, on the left and right respectively. At test, the landmarks were switched within or across junctions. Participants were released at each intermediate junction and were required to make a decision on their walking direction. The results showed that people might have made their judgments by integrating movements related to separate views (front, left, or right) in a voting scheme. It was also suggested that participants did not learn the sequence of landmarks because when landmarks from two junctions were switched, most of the participants did not report the change.

Other findings, however, suggested that people might be able to learn the sequence of landmarks (e.g., Albert et al., 1999; Buchner and Jansen-Ossman, 2008; Cousins et al., 1983; Janzen and Janson, 2010). Janzen and Janson (2010) demonstrated that people could distinguish between two identical landmarks at different decision points (e.g., turn left at the first Landmark A and turn right at the second Landmark A). People might use the knowledge of landmark sequence to differentiate the two identical landmarks.

As reviewed above, there are three types of landmark knowledge that could be used in humans' direction choice at decision points. First, people used a landmark as a beacon. Second, people used a landmark as an associative cue. Last, people used the sequence of landmarks to distinguish identical landmarks. However, studies are rare that systematically examined how these types of landmark knowledge are developed with increasing experience in an environment (Waller & Lippa, 2007).

Trullier et al. (1997) proposed that there are four levels of navigation strategies: guidance, place recognition-triggered response, topological navigation and metric navigation and these four levels of strategies are developed in a successive order. Only the first three will be discussed in this paper, as metric information between landmarks is not essential in direction choice at decision point in a route following behavior. Guidance was first defined by O'Keefe and Nadel (1978) as a process of maintaining certain egocentric relationship to a goal or distinctive landmarks. This simplest strategy has been found to be widely used by animals (e.g., Collett et al., 1992). At this level, navigators do not need to know where they are in the environment. A higher level of navigation strategy is called place recognition-triggered response. Place recognition triggers an action that is associated with the memorized direction to the goal from that place. At this level, navigators do not know the relations between the current place and other places in the environment. The third level is topological navigation, which involves the knowledge of the sequence of places (Collett et al., 1993). At this level, navigators develop place-action-place association. Hence after recognizing a place, navigators not only produce the recognition-triggered response, but can also anticipate the place where they will arrive next.

These three levels of strategies correspond to the three kinds of landmark knowledge distinguished in humans' direction choice behavior discussed above. Firstly, guidance corresponds to the beacon knowledge if participants could learn not only to approach a beacon but also to avoid a beacon (i.e., choose the door further from the beacon) in the study of Waller and Lippa (2007). Therefore, the beacon knowledge represents the association between a landmark and an action of avoiding/approaching the landmark and supports guidance. Secondly, the place recognition-triggered response conceptually corresponds to landmark as an associated cue to decide a direction if we assume a landmark as an associative cue defined a place in the study of Waller and Lippa (2007). Therefore, the landmark-action association is the same as place-action association (e.g., at place A, turn left). Finally, the knowledge of landmark sequence (i.e., place A, place B, place C and so on) represents the sequence of landmarks or places and supports topological navigation.

Similar to Trullier et al. (1997), Siegel and White (1975) also proposed that different types of spatial knowledge are developed in a qualitative transition sequence (see also, Hart & Moore, 1973). According to their theory, spatial knowledge in a large-scale environment is divided into landmark, route and survey knowledge (Siegel & White, 1975). First, different landmarks are distinguished and remembered by an individual; then the individual's movements are associated with specific landmarks (landmark-action association, e.g., turning left when seeing landmark A); then landmarks are encoded in subsystems of reference which are not coordinated as a whole (landmark-place association); and finally routes are coordinated in an objective frame of reference (place-place association) and form a survey map. This theoretical framework has been supported by some empirical research (Appleyard, 1970; Lynch, 1960; Siegel & Schadler, 1977).

However, in contrary to the Siegel and White's framework, Ishikawa and Montello (2006) (see also Montello (1998)) proposed that all types of spatial knowledge can be developed from the beginning of navigation simultaneously. Their study showed that survey knowledge could be developed at the beginning of navigation and for some participants it can be developed quite well with minimal exposure to the environment.

Following Trullier et al. (1997) and Siegel and White (1975), we hypothesized that human may develop the three types of landmark knowledge that are used in humans' direction choice behavior at different rates as they correspond to different developmental stages: (1) guidance, which depends on knowledge about landmark-action association; (2) place recognition-triggered response, which depends on knowledge about landmark-place association; and (3) topological navigation, which depends on knowledge about place-place association. In particular, the knowledge for guidance might develop first, followed by the knowledge for place recognition-triggered response, and knowledge of landmark sequence might develop last. This hypothesis was partially supported by the findings of Waller and Lippa (2007).

The current study aimed to more systematically test whether humans develop the types of landmark knowledge at different stages. Two experiments were designed to dissociate different types of landmark knowledge at decision points and examine their development trajectory.

2. EXPERIMENT 1

In an immersive virtual environment, participants learned a route with 12 intersections and at each intersection there was one distinctive landmark (see Figure 1). At test, participants were placed at each intersection in the same order as in the learning phase, which participants were explicitly informed of. Participants were required to make turns. The landmarks at different intersections were manipulated in three conditions, in which the landmarks were removed (no landmark), correctly presented (one landmark), or duplicated and presented on both sides (two identical landmarks) (see Figure 2). The 12 intersections were randomly assigned to one of the three conditions, with the restriction that each condition included the same number of intersections.

The landmark knowledge for guidance is the knowledge for avoiding/approaching a landmark. It can be used to predict the correct turning direction only when a landmark is correctly placed as in the one landmark condition. In the two identical landmarks condition, the two landmarks predict the opposite directions. Last, in the no landmark condition, there is no visual cue in the local view that could support guidance. As a result, if participants only

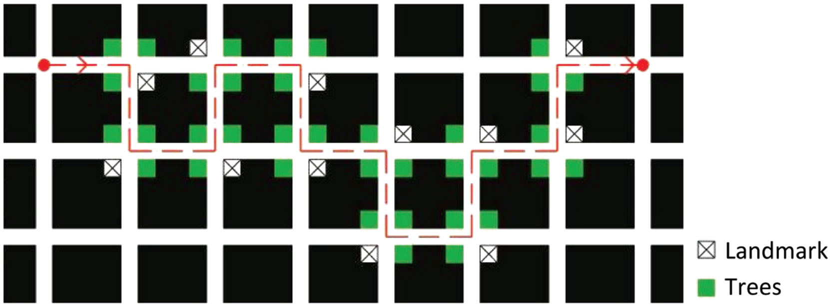

Figure 1. Plan of city and an example of the routes (color figure available online).

developed the landmark knowledge for guidance, then it would predict better performance in the one landmark condition than in the other two conditions. Performance in the other two conditions should not differ.

The landmark knowledge for place recognition represents the association between landmark identity and place, and supports place recognition-triggered response (e.g., at place A, turn left). In both one landmark and two identical landmarks conditions, participants can recognize places with the presence of the landmark and can correctly predict the turning direction. If participants fully developed the landmark knowledge for place recognition, then the predicted performance in the one landmark condition and in the two identical landmarks condition should be comparable.

The knowledge of landmark sequence represents the sequence of landmarks or places (i.e., place A, place B, place C, and so on). Even in the no landmark intersection, participants can retrieve the landmark information using the sequence of the landmarks, and hence know the current intersection

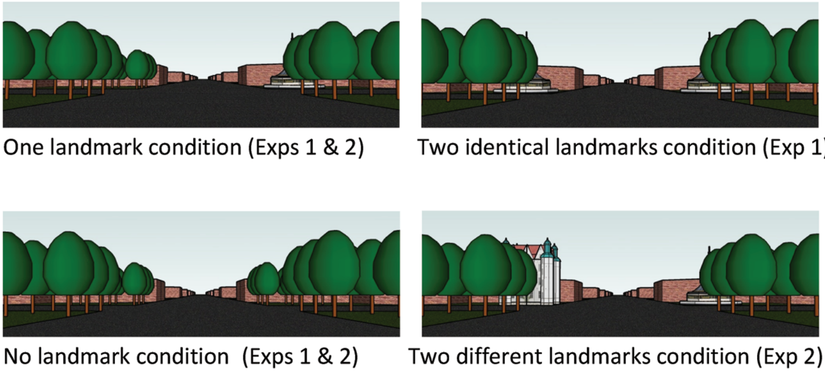

Figure 2. Conditions of presenting landmarks at test. The view in the one landmark condition was the same across learning and test (color figure available online).

and select the correct turning direction using the knowledge of place-response association discussed in the previous paragraph. If participants fully developed the knowledge of landmark sequence, then the predicted performance should be comparable in all conditions.

In addition to the landmark knowledge, people might also develop some knowledge of movement sequence in navigation (e.g., turn left at the first intersection, then turn right at the second intersection) regardless of landmark information. Hence, even if participants did not develop any knowledge of landmark sequence, their performance in the no landmark condition would still be above chance level. If participants fully developed the knowledge of movement sequence, then the predicted performance should be comparable in all conditions. In this case, we were unable to dissociate whether participants fully developed the knowledge of landmark sequence, the knowledge of movement sequence, or both.

As we planned to test whether full development of different kinds of landmark knowledge requires different amount of navigation experience, we manipulated the navigation times and expected that different types of landmark knowledge would be observed with different navigation times.

2.1. Method

2.1.1. Participants. Ninety-six university students (48 men and 48 women) participated in this experiment as partial fulfillment of a requirement in an introductory psychology course.

2.1.2. Materials and Design. The experiment was conducted in a room of 4m by 4m. A physical chair was placed in the middle of the room. A virtual gridlike city was displayed in stereo with an nVisor SX60 head-mounted display (HMD, NVIS, Inc. Virginia). Participants' head motion was tracked with an InterSense IS-900 motion tracking system (InterSense, Inc., Massachusetts) so that they could look around in the city. The city was divided into 90 m by 90 m blocks by streets that were 10 m wide (Figure 1). Participants learned one route in the city. The route consisted of 12 intersections. The correct movement at each intersection was either a left or right turn but never in a straight direction. There were equal numbers of left and right turns. There were no three intersections with the same turning direction in a row. Four different routes were used across participants. Each intersection consisted of one salient landmark and three groups of trees. For each participant, landmarks at individual intersections were randomly presented in the front left or front right corner in terms of the participant's heading. At each intersection, the test heading of the participants was the same as their heading when they approached this intersection. Their test location was 30m away from the center of the intersection.

Participants were randomly assigned to two groups, where they either learned the route once or five times, with an equal number of males and females in each group.

There were three ways of presenting landmarks at test (Figure 2): one landmark condition in which nothing was changed, no landmark condition in which landmarks were replaced by trees, or two landmarks condition in which the landmarks were duplicated on the opposite side of the roads so that there were two identical landmarks in the front left and front right. For each participant, each intersection was randomly assigned to one of these three conditions, with the restriction that the number of intersections in each condition was the same.

2.2. Procedure

Wearing a blindfold, the participants were guided into the testing room and seated on the chair. Participants donned the HMD and then removed the blindfold. Participants were instructed to imagine themselves as a passenger who would traverse a route in a car and to remember the route they would pass so that they could reproduce the route by themselves starting from the same departure location and heading direction. Before the learning phase, participants were explicitly told that at test they would be transported to each intersection in the learning order, and that they would be put to the next correct intersection, even if they made the wrong turn. Participants were not informed that the landmarks at test might change to avoid them from intentionally abandoning landmark related strategies. The location of the participants (or car) in the route was changed at a constant speed by the computer. Participants' initial orientation was aligned with the moving direction of the car, but participants could look around during their movement.

After learning the route once or five times, participants were released at the first intersection initially and were instructed to choose the turning direction to reach the next intersection by clicking the left or right mouse button. After they had made a response, the screen on the HMD turned blue for two seconds and participants were then released at the second correct intersection and so on. No feedback was given and accuracy was recorded.

2.3. Results and Discussion

Mean percentage of correct judgment as a function of landmark and learning time is plotted in Figure 3. As illustrated in the figure, there are two important findings: (1) In the group which learned the route once, performance was better in the one landmark condition than in the other two conditions, and performance in the other two conditions did not differ; (2) In the group that learned the route five times, performance in the one landmark condition and

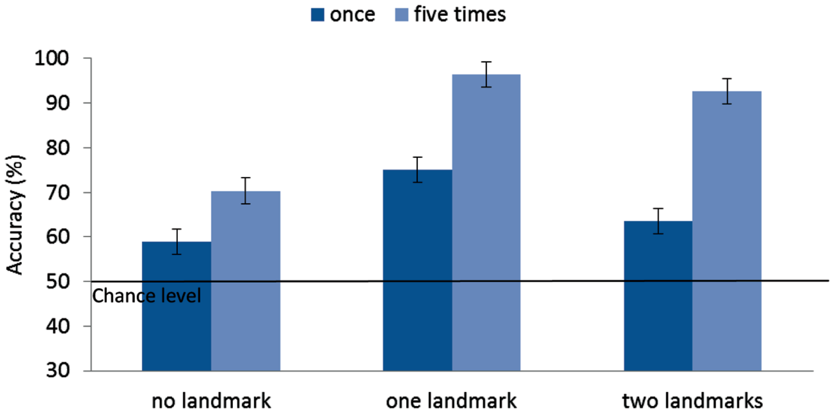

Figure 3. Correct percentage of turning directions as the function of learning times and landmark in Experiment 1 (color figure available online).

in the two landmarks condition were comparable, and both were better than in the no landmark condition. These findings were supported by the statistical analyses.

The mean accuracy in each condition was analyzed in mixed model ANOVAs with terms for landmark and learning time. Landmark is within subject and learning time is between subject variable.

The main effect of learning time was significant, $F(1, 94) = 44.20$, $MSE = .07$, $p < .001$, $\eta_p^2 = .32$. The main effect of landmark was significant, $F(2, 188) = 28.07$, $MSE = .04$, $p < .001$, $\eta_p^2 = .23$. The interaction between landmark and learning time was significant, $F(2, 188) = 4.84$, $p < .01$, $\eta_p^2 = .05$. Specifically, the interaction was due to the larger effect of the learning time in the two landmarks condition than in the no landmark condition, $F(1, 188) = 9.63$, $p < .01$.

For the participants who learned the route once, accuracy was significantly higher in the one landmarks condition than in the other two conditions, $t\text{s}(188) = 2.84$, $p\text{s} < .01$. Accuracy did not differ in the two latter conditions, $t(188) = 1.16$, $p = .25$. This result suggested that the participants who learned the route once used guidance (i.e., turn towards/away from a landmark) but not place recognition-triggered response (i.e., turning left/right at place A).

For the participants who learned the route five times, the difference in accuracy between the two landmarks condition and the one landmark condition was not evident, $t(188) = .90$, $p = .37$. This result suggested that the participants who learned the route five times used place recognition-triggered response. The accuracy in both conditions was significantly better than that in the no landmark condition, $t\text{s}(188) \geq 5.55$, $p\text{s} < .001$.

The first finding suggested that participants only fully developed landmark knowledge for guidance when they learned the route only once. The second finding suggested that participants fully developed landmark knowledge for place recognition when they learned the route five times. Note that there are three important procedure differences between the current study and Waller and Lippa's study (2007). First, in the current study, participants could learn both knowledge for guidance and knowledge for place recognition-triggered response, whereas participants in Waller and Lippa's study learned either knowledge for guidance or knowledge for place recognition-triggered response.

Second, in the current study the correct turn could be on the same or different side of the landmark so that we can test whether the beacon could be used as an avoiding cue as well as an approaching cue. Finally, in the current study two identical landmarks were used at the same decision point so that participants need to use the landmark to determine a place and use the place-response association. Regardless of these differences, both studies showed that participants developed knowledge for guidance earlier than knowledge for place recognition-triggered response.

In addition, we did not observe comparable performance in the three conditions of landmark, even after participants learned the route five times. Hence, participants might not fully develop either the knowledge of landmark sequence or the knowledge of turning sequence after learning five times.

However, there was some evidence showing that participants developed some knowledge of sequence whether it is about sequence of turns or sequence of landmarks. The accuracy in the no landmark condition was above chance level even for participants who only learned once, $t(47) = 2.27$, $p < .05$. Furthermore, the performance in the no landmark condition was significantly better for participants who learned five times than participants who learned once, $t(94) = 2.036$, $p < .05$. These results indicated that participants who learned once developed some knowledge of sequence and participants who learned five times developed better knowledge of sequence.

It was not clear whether the knowledge of sequence is the sequence of movements (e.g., turn left at the first intersection, then turn right at the second intersection), the sequence of landmarks, or both. If participants learned some knowledge about the sequence of turns, they could make turns even when there was no landmark presented. If they learned the knowledge of landmark sequence, participants could infer the missing landmark at the no landmark decision point from the landmarks presented in the previous intersections. Experiment 2 was designed to address this issue.

3. EXPERIMENT 2

To distinguish whether the better than chance performance in the no landmark intersections in Experiment 1was due to sequential knowledge of landmarks or turns, we manipulated the order of landmarks presented at test in Experiment 2. The effective use of landmark sequence knowledge is vulnerable to the disruption of the order in which the landmarks were presented at test, yet the effective use of the movement sequence knowledge will not be affected by the disruption of the order of landmarks.

Experiment 2 was identical to Experiment 1 except that at test, each landmark that was removed at the four no landmark intersections was added to another intersection, such that two different landmarks were presented at four intersections, thus replacing the condition of two identical landmarks in Experiment 1 (see Figure 2). Hence, the presentation orders of landmarks at study and test were not the same. If participants only developed knowledge of movement sequence but not knowledge of landmark sequence, then the performance in the no landmark condition should demonstrate the same pattern (e.g., the same learning time effect) as observed in Experiment 1 as the disruption of presentation order does not impair use of the movement sequence knowledge. Any different pattern in the no landmark condition would indicate the knowledge of the landmark sequence.

3.1. Method

3.1.1. Participants. Ninety-six university students (48 men and 48 women) participated in this experiment as partial fulfillment of a requirement in an introductory psychology course. None of them had participated in Experiment 1.

3.1.2. Materials, Design, and Procedure. The materials, design, and procedure in experiment 2 were identical to experiment 1 except that there were two different landmarks indicating opposite turning directions in the two landmarks condition (see Figure 2). One was the original landmark and the other was the landmark that was removed from an adjacent intersection that then became the no landmark intersection.

To implement this modification, two new routes were created. In these routes, 12 intersections were divided evenly into four groups (i.e., 1-2-3, 4-5-6, 7-8-9, and 10-11-12). In each group, the three conditions were randomly assigned to the three intersections with the restriction that the no landmark and two landmarks condition should be assigned to adjacent intersections (e.g., one landmark-two landmarks-no landmark, or two landmarks-no landmark-one landmark), and turning direction in adjacent intersection should be different (e.g., left-right-left, or right-left-right).

4. RESULTS AND DISCUSSION

Mean percentage of correct judgment as a function of landmark and learning time is plotted in Figure 4. As illustrated in the figure, there are two important

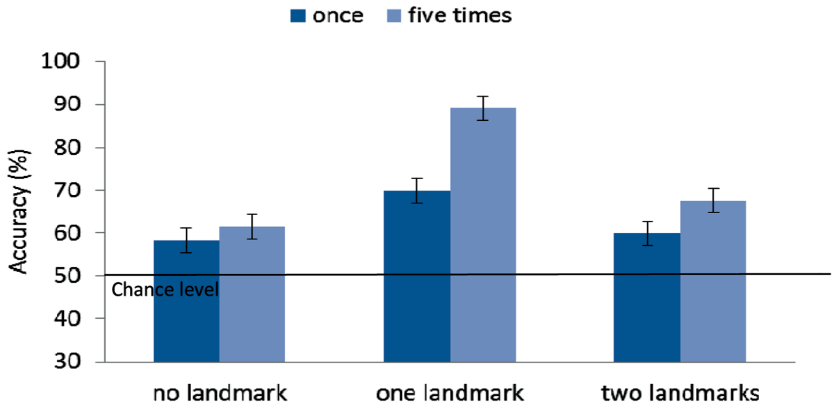

Figure 4. Correct percentage of turning directions as the function of learning times and landmark in Experiment 2 (color figure available online).

findings: (1) the performance was comparable for both learning groups in the no landmark condition, and (2) the performance was above chance level in the no landmark condition even for participants who learned the route once.

The mean accuracy in each condition was analyzed in mixed model ANOVAs with terms for landmark and learning time. Landmark is within subject and learning time is between subject variable.

The main effect of learning time was significant, $F(1, 94) = 6.11$, $MSE = .12$, $p < .05$, $\eta_p^2 = .06$. The main effect of landmark was significant, $F(2, 188) = 26.62$, $MSE = .04$, $p < .001$, $\eta_p^2 = .22$. The interaction between landmark and learning time was significant, $F(2, 188) = 4.30$, $p < .05$, $\eta_p^2 = .04$. The effect of the learning time was larger in the one landmark condition than in the no landmark condition, $F(1, 188) = 8.12$, $p < .01$. The effect of the learning time was also larger in the one landmark condition than in the two landmarks condition, $F(1, 188) = 4.09$, $p < .05$. For both learning groups, accuracy was significantly higher in the one landmark condition than in the other two conditions, $t\text{s}(188) \geq 2.47$, $p\text{s} < .05$. Accuracy in both learning groups did not differ in the latter two conditions, $t\text{s}(188) \leq 1.56$, $p\text{s} \geq .12$. Consistent with the findings in Experiment 1, these results suggested that the participants did not fully develop either knowledge of landmark sequence or knowledge of movement sequence even after learning five times.

More importantly, performance in the no landmark condition was not significantly better in the group that learned five times than in the group which learned once, $t(94) = .53$, $p = .60$, which was inconsistent with Experiment 1. If only knowledge of turning sequence was used in the no landmark intersections in Experiments 1 and 2, there should be the same superiority of the group which learned five times in Experiment 2 as that in Experiment 1. Hence, the difference in the no landmark condition between the two learning groups observed in Experiment 1 but not in Experiment 2 suggested that people developed some knowledge of landmark sequence that could be used in Experiment 1 in which the order of landmarks remained the same at test, but not in Experiment 2 in which the order of landmarks was disrupted at test. However, the accuracy in the no landmark condition was still above chance level even for participants who learned only once, $t(47) = 2.14$, $p < .05$, which was also observed in Experiment 1. This result indicated that participants developed some knowledge of turning sequence when they learned the route once.

5. GENERAL DISCUSSION

The purpose of this study was to investigate how different types of landmark knowledge that are used in direction choices at decision points of a route develop with navigation experience. Three different types of landmark knowledge were examined: landmark knowledge for guidance, landmark knowledge for place recognition, and knowledge of landmark sequence, as inspired by the successive development models (Siegel & White, 1975; Trullier et al., 1997) and previous human route-following studies (e.g., Waller & Lippa, 2007). There are three important findings: (1) Participants who learned the route once demonstrated landmark knowledge for guidance; (2) Participants who learned the route five times demonstrated accurate landmark knowledge for place recognition; (3) Participants who learned the route five times demonstrated some coarse knowledge of landmark sequence.

Participants demonstrated landmark knowledge for guidance but not landmark knowledge for place recognition after learning the route once. Use of landmark knowledge for guidance was supported by the better performance in the one landmark condition than in the no landmark condition and two identical landmarks condition in Experiment 1, as participants could only use guidance effectively (i.e., towards or away from a landmark) in the one landmark condition but not in the other two conditions. Moreover in Experiment 1, participants who learned the route once did not perform better when they saw two identical landmarks than when they saw no landmark. This finding indicated that these participants did not use the landmark knowledge for place recognition. Otherwise, participants should perform better when they saw two identical landmarks, as the landmarks convey information that was sufficient for place recognition.

By contrast, participants who learned the route five times demonstrated accurate landmark knowledge for place recognition. In Experiment 1, the participants who learned the route five times had comparable accuracy in the two identical landmarks condition and in the one landmark condition. These results indicated that participants could recognize places with the presence of two identical landmarks and used place-response association to make the correct turns. If participants did not develop accurate landmark knowledge for place recognition-triggered response, the performance should have been worse in the two identical landmarks condition than in the one landmark condition because the two identical landmarks as a beacon provided conflicting turning information.

After learning the route five times, participants were able to demonstrate coarse knowledge of landmark sequence. In Experiment 1, the participants who learned the route five times performed better in the one landmark condition than in the no landmark condition, which indicated that they did not fully developed knowledge of landmark sequence. However, the participants who learned the route five times performed better than the participants who learned the route once in the no landmark condition. Furthermore, this difference was not due to the improvement of the knowledge of movement sequence, as this difference was not observed when the landmark order was disrupted in Experiment 2. Hence, this difference suggested that participants developed some coarse knowledge of landmark sequence.

In this study, there is clear evidence indicating that people can develop the three different types of landmark knowledge. We acknowledge that the current study did not provide evidence to show that people could fully develop knowledge of landmark sequence as we only used 1 and 5 trials of learning. Previous research showed that people may need substantial experience (Cousins et al., 1983) and full attention (Albert et al., 1999) to develop accurate knowledge of landmark sequence. Buchner and Jansen-Ossman (2008) found that learning landmark sequence is more efficient when they are dynamically displayed in a route with full context and segments with different length. Future studies are needed to determine the required number of learning trials that is sufficient for people to demonstrate accurate knowledge of landmark sequence in the current paradigm.

Mallot and Gillner (2000) proposed that people use a voting scheme to select the turning direction at a decision point with different landmarks. In their hypothesis, a turning direction is associated with a landmark in a specific view. For example, in a Y-shaped intersection, people learned to turn right when they saw a green building on the left, and turn left when they saw the green building in the front when travelling in the opposite direction along the same route. No action is triggered when they saw the green building on the right view. This voting scheme might be used in the two different landmarks condition in Experiment 2.

Two different landmarks were located at the correct side of the intersection and indicated two opposite turning directions in the two different landmarks condition, leading to worse performance than that in the one landmark condition. This voting scheme can also be used in the two identical landmarks condition in Experiment 1. The landmark presented at the correct position indicated the correct turning direction, yet the same landmark presented at the incorrect position did not indicate any directional information, leading to comparable performance in the one landmark and two identical landmarks condition when participants learned the route five times.

The results in our experiments appear to be consistent with the successive development model proposed by Siegel and White (1975) in terms of the development of landmark knowledge. Siegel and White proposed that an action is registered with a landmark in an earlier stage, then the landmark may be represented in a local frame of reference and associated with a place. At a later stage, connections among places are coordinated within a global frame of reference and form a topological or survey map. Our finding supports this theory in that guidance, which depends on knowledge about landmark-action association, is learned with minimal experience; place recognition-triggered response, which depends on knowledge about landmark-place association, is learned with more experience; and topological navigation, which depends on knowledge about place-place association, is insufficiently learned even with five trials of learning. However, the findings of the current study do not necessarily contradict to the theory of Ishikawa and Montello (2006). According to Ishikawa and Montello (2006), people might develop all kinds of knowledge (i.e., landmark, route, and survey knowledge) simultaneously.

We acknowledged that our conclusion might only apply to the development of landmark knowledge but not to the development of route and survey knowledge on which Ishikawa and Montello (2006) focused. Furthermore, in the current study, we focused on group comparison instead of individual level analyses. As suggested in Ishikawa and Montello's (2006) study, individual difference is a huge factor in human navigation that should not be ignored. Future research is needed to examine whether good and poor navigators develop landmark knowledge in the same pattern.

The findings in the current study converged with those of Waller and Lippa (2007). Both studies showed that learning beacon or knowledge for guidance was quicker than learning associative cue or knowledge for place recognition. In Waller and Lippa's (2007) study, participants in the beacon condition did not need to encode the appropriate action at a landmark as they only approached the landmark, whereas participants in the associative cue condition needed to encode the appropriate action at a landmark as the location of the landmark did not indicate the correct response directly. However, the ease of learning in the beacon group might not be due to the fact that participants in this group did not need to encode the response with respect to the landmark whereas participants in the associative cue group did. In the current study, participants had to encode response (approaching or turning away) with respect to the landmark but we still found the ease of beacon learning than place recognition learning.

We speculated that the ease of beacon learning than place recognition learning might occur because the former does not require a specific walking direction whereas the latter does. People can approach or avoid a landmark without knowing their orientation in the environment. However, in order to select the correct response at a place, people have to know their orientation in the environment. If they accidentally run into the place from a direction different from the route they used to travel, and cannot reorient themselves, then the associated action will lead to a wrong destination. In this case, guidance seems to be a more guaranteed navigation strategy in an unfamiliar environment. Data from route description show that people use both strategies to describe actions referred to landmarks (Tom & Denis, 2004). Further research may examine whether one of the strategies is used more often in route description.

The finding in the current study also suggests that the knowledge of landmark sequence is developed slower than the other two kinds of landmark knowledge. One possible reason might be that the knowledge of landmark sequence (i.e., place A, place B, place C and so on) cannot indicate movement direction at a specific intersection. When people recognize a place using the knowledge of landmark sequence, they still need to rely on the knowledge of place-response association to decide the movement direction. Thus, they may develop accurate knowledge of landmark sequence in a later stage or at a slower speed than the knowledge of place-response association (i.e., knowledge for place recognition-triggered response).

In summary, the findings of the current study have demonstrated that humans develop three types of landmark knowledge that can be used in selection of directions at decision points: landmark knowledge for guidance, landmark knowledge for place recognition, and knowledge of landmark sequence. These three types of knowledge require different navigation experience: guidance develops earlier than place recognition, and place recognition develops earlier than landmark sequence.

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