Distinction of Landmark Knowledge at Decision Points

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Abstract

Two experiments distinguished different landmark knowledge of human adults at decision points. Participants learned a route in a virtual city once or for 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.
Landmark knowledge is important for navigation. People use landmarks to determine their locations and orientation in a route, to choose their moving directions at decision points, and to anticipate the subsequent segments of the route (e.g. Janzen & Jansen, 2010; Janzen & van Turennout, 2004; Mallot & Gillner, 2000; Ruddle, Volkova, Mohler, & Bülthoff, 2011; Siegel & White, 1975; Thorndyke & Hayes-Roth, 1982; Tolman, 1946; Waller & Lippa, 2007). In the current study, we focused on the landmark function in direction selection at decision points.

Mallot and Gillner (2000) studied how people use landmarks to decide on their turning direction at the 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 the landmarks from two junctions were switched, most of the participants did not report the change.

Janzen and van Turennout (2004) examined the neural basis of using landmarks at the decision point. Participants first saw objects at decision points and at non-decision points in a route and then they were tasked to recognize the objects from distracter objects in MRI scanner. The results showed that parahippocampal responses were selectively increased for objects at decision points. Janzen and Janson (2010) demonstrated that people could distinguish between two identical landmarks at different decision points. People might use the knowledge of landmark sequence to
differentiate the two identical landmarks.

Although empirical evidence indicated that people rely on landmark knowledge to select correct direction at decision points, there are rare studies that systematically examined different types of landmark knowledge that might be used to choose directions at decision points (Waller & Lippa, 2007). In this study, we distinguished three types of landmark knowledge: knowledge for guidance, knowledge for place recognition, and knowledge of landmark sequence. This distinction was derived from the model proposed by Trullier et al. (1997).

Reviewing the animal literature, Trullier et al. (1997) proposed that there were four levels of navigation strategies: guidance, place recognition-triggered response, topological navigation and metric navigation. Only the first three will be discussed, as they are relevant to landmarks. 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, animals 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, animals do not know the relations between the current place and other places in the environment. The third level is topological navigation, which involves route knowledge such as the sequence of places (Collett et al., 1993). At this level, animals develop place-action-place association. Hence after recognizing a place, animals 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 the current study. In particular, the landmark knowledge for guidance represents the association between landmarks and actions of avoiding/approaching and supports guidance. The landmark knowledge for place recognition represents the association between landmark and place, and supports place recognition triggered response. The knowledge of landmark sequence represents the sequence of landmarks or places and supports topological navigation.

We assumed that full development of these three types of landmark knowledge require different amount of navigation experiences (Trullier et al., 1997) although these three kinds of knowledge might start to develop simultaneously (Ishikawa & Montello, 2006). Specifically, landmark knowledge for guidance might be fully developed with relatively short navigation experiences, landmark knowledge for place recognition with more navigation experiences, and knowledge for landmark sequence with relatively long navigation experiences. This assumption is partially supported by the study of Waller and Lippa (2007). In this study, participants made left and right decision at the presence of landmarks in a desktop VR environment. In the associative cue condition, they needed to associate the direction decision with the presence of one landmark (e.g. turn left at item A), whereas in the beacon condition, they needed to approach the direction indicated by one of two landmarks (e.g. go to the direction indicated by item A). The results showed that people learned quicker in the beacon condition than in the associative cue condition. We conjecture that the associative cue in their study was analog to the landmark knowledge for place recognition in the current study, whereas the beacon in their study belongs to the landmark knowledge for guidance in the current study because guidance could include both approaching (i.e. beacon) and avoiding a landmark.

Two experiments were designed to provide evidence for these distinctions of
landmark knowledge at decision points.

Experiment 1

In an immersive virtual environment, participants learned a route with twelve intersections and at each interaction 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. Participants were required to make turns. The twelve intersections were randomly divided into three groups. Each group consisted of four intersections and participants were randomly assigned to one of the three conditions, in which the landmarks were either removed (no landmark), correctly presented (one landmark), or duplicated and presented on both sides (two identical landmarks) (See Figure 2).

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. Lastly, in the no landmark condition, the landmark knowledge for guidance cannot be used. As a result, if participants 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 and place, and supports place recognition triggered response. In both the one landmark and two identical landmark conditions, participants can recognize places with the presence of the landmark and can correctly predict the turning direction. However, place recognition is not possible in the no-landmark condition. 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, and both should be better than that in the no landmark condition.

The knowledge of landmark sequence represents the sequence of landmarks or places. Even in the no landmark intersection, participants can retrieve the landmark information using the sequence of the landmarks and the number of intersection, and hence know the current intersection and select the correct turning direction using the lower levels of landmark knowledge. 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 assumed that 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.

**Method**

*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.

*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 grid-like 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 90m by 90m blocks by streets that were 10m 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 in 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 participant 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 for 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. Four of the twelve intersections were randomly assigned to each of the three conditions.

**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. The location of the participants (or car) in the route was changed in 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 for 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 intersection and so on. Accuracy was recorded.

**Results and Discussion**

Mean percentage of correct judgment as a function of landmark and learning times is plotted in Figure 3. As illustrated in the Figure, there are three 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 which learned the route for five times, performance in the one landmark condition and in the two
landmark condition were comparable, and both were better than that 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 times. Landmark is within subject and learning times is between subject variable.

The main effect of learning time was significant, $F(1, 94) = 44.20, MSE = .07, p < .001, \eta^2_p = .32$. The main effect of landmark was significant, $F(2,188) = 28.07, MSE = .04, p < .001, \eta^2_p = .23$. The interaction between landmark and learning times was significant, $F(2,188) = 4.84, p < .01, \eta^2_p = .05$.

For the participants who learned the route once, accuracy was significantly higher in the one landmark condition than in the other two conditions, $t(188) \geq 2.84, ps < .01$. 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.

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

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

However, there was some evidence showing that participants developed some knowledge of sequence. 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 was significantly better for participants who learned for 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 for 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. Therefore, experiment 2 was designed to address this issue.

Experiment 2

We assumed that the effective use of landmark sequence knowledge is vulnerable to the disruption of the order in which the landmarks were presented at test, while the effective use of the movement sequence knowledge will not be affected by disordered landmarks. Experiment 2 was identical to experiment 1 except that at test the landmarks that were removed at one intersection were added to another intersection, such that two different landmarks were presented (two different landmarks), thus replacing the condition of two identical landmarks in Experiment 1. Hence, the presentation orders of landmarks at study and test were not the same. If participants only developed knowledge of movement sequence, then the performance
in the no landmark condition should demonstrate the same pattern as observed in Experiment 1 as the disruption of presentation order does not impair use of the movement sequence knowledge. Any difference in pattern in the no landmark condition should indicate the knowledge of the landmark sequence.

Method

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.

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 landmark condition (See Figure 2). One was the original landmark and the other was the landmark that was removed from the intersections of the no landmark condition. To implement this modification, two new routes were created. In these routes, there were different turning directions in the adjacent intersection for every three intersections (e.g. left-right-left for the first and second three intersections, right-left-right for the third and fourth three intersections). The three landmark conditions were randomly assigned to the intersections in each of the four groups of three intersections with the restriction that the no landmark and two landmark conditions should be assigned to the adjacent intersections.

Results and Discussion

Mean percentage of correct judgment as a function of landmark and learning times is plotted in Figure 4. As illustrated in the figure, there are two important findings: 1. The performance was comparable for both learning groups in the no
landmark condition; 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 times. Landmark is within subject and learning times is between subject variable.

The main effect of learning time was significant, $F(1, 94) = 6.11$, $MSE = .12$, $p < .05$, $\eta^2_p = .06$. The main effect of landmark was significant, $F(2,188) = 26.62$, $MSE = .04$, $p < .001$, $\eta^2_p = .22$. The interaction between landmark and learning times was significant, $F(2,188) = 4.30$, $p < .05$, $\eta^2_p = .04$.

For both learning groups, accuracy was significantly higher in the one landmark condition than in the other two conditions, $t(188) \geq 2.47$, $ps < .05$. Accuracy in both learning groups did not differ in the latter two conditions, $t(188) \leq 1.56$, $ps \geq .12$. 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 for five times.

More importantly, performance in the no landmark condition was not significantly better in the group which learned for five times than in the group of learning once, $t(94) = .53$, $p = .60$, which was inconsistent with Experiment 1. The difference between the two learning groups was observed in Experiment 1 but not in Experiment 2, which suggested that people developed some knowledge of landmark sequence that could be used in Experiment 1 but not in Experiment 2. 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.
General Discussion

The purpose of this study is to distinguish three different types of landmark knowledge: landmark knowledge for guidance, landmark knowledge for place recognition, and knowledge of landmark sequence, as inspired by the animal model proposed by Trullier et al. (1997). There are three important findings: 1. Participants who learned the route once demonstrated landmark knowledge for guidance; 2. Participants who learned the route for five times demonstrated accurate landmark knowledge for place recognition; 3. Participants who learned the route for five times demonstrated some coarse knowledge of landmark sequence.

Participants demonstrated the landmark knowledge for guidance but not the landmark knowledge for place recognition after learning the route once. Use of the landmark knowledge for guidance was supported by the better performance in the one landmark condition than in the no landmark condition and two identical landmark 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.

The participants who learned the route for five times demonstrated accurate landmark knowledge for place recognition. In Experiment 1, the participants who learned the route for five times had comparable accuracy in the two identical landmarks condition and in the one landmark condition, and the performance in both
condition were better than that in the no landmark condition. This finding indicated that participants could recognize places with the presence of the landmark regardless of the locations of the landmarks.

After learning the route for five times, participants were able to demonstrate coarse but not accurate knowledge of landmark sequence. In Experiment 1, the participants who learned the route for 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 for 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 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 could learn the sequence of landmarks with remarkable experience (Cousins et al., 1983) and full attention (Albert et al., 1999). 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. This voting scheme might be used in the two different landmarks condition in Experiment 2, as the two
different landmarks were located at the correct side of the intersection and indicated two opposite turning directions, leading to the 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 if we assume a higher voting weight is assigned to the correct location and the correct location is remembered better with more learning trials.

Janzen and Jansen (2010) reported that people have a neural mechanism to differentiate two identical objects at two decision points. The participants in their experiment might have used the sequence knowledge to differentiate two identical objects at different decision points, which was consistent with the findings of the current study. The current study indicated that participants could use the sequence knowledge to determine the turning direction in the no landmark condition.

The dissociation between the landmark knowledge for guidance and the landmark knowledge for place recognition is consistent with the distinction between landmarks as beacon and landmarks as associative cues proposed by Waller and Lippa (2007). The only difference is that in their study, the beacon is the landmark to approach whereas in the current study, guidance could be approaching a landmark or avoiding a landmark (see Figure 1). Regardless of this difference, both studies showed that learning beacon or guidance was quicker than learning associative cue or knowledge for place recognition. Hence, this may indicate that beacon learning in Waller and Lippa (2007) might indeed develop the landmark knowledge for guidance.

In the current study, participants were transported to different intersection during learning like a passenger in a car. Hence, their learning is relatively passive such that participants did not control their location or make decision of their turns. We are not sure whether the finding in the current study could be generalized to the
conditions in which participants learn the route by actively control their navigation (e.g. driving a car using a joystick or a game steering wheel) and by selecting the route. Chrastil and Warren (2012) proposed that idiothetic information contributes to metric survey knowledge but decision making (e.g. select the route) does not contribute to route or survey knowledge. It is not clear how idiothetic information actively controls the navigation interface and how decision making in selection of a route affects the development of the three types of knowledge distinguished in the current study.

In summary, the findings of the current study have demonstrated that humans develop landmark knowledge for guidance, landmark knowledge for place recognition, and knowledge of landmark sequence, which support guidance, place recognition-triggered response, and topological navigation. These results might suggest humans also use these three levels of landmark strategies as proposed by Trullier et al. (1997) in their animal model.
References


Figure Captions

Figure 1. Plan of city and an example of the routes.

Figure 2. Conditions of presenting landmarks at test. The view in the one landmark condition was the same across learning and test.

Figure 3. Correct percentage of turning directions as the function of learning times and landmark in Experiment 1.

Figure 4. Correct percentage of turning directions as the function of learning times and landmark in Experiment 2.
Figure 1

Landmark
Trees
Figure 2

One landmark condition (Exps 1 & 2)  Two identical landmarks condition (Exp 1)
No landmark condition  (Exps 1 & 2)  Two different landmarks condition (Exp 2)
Figure 3

The graph shows the accuracy percentage for different landmark conditions with and without repetition. The accuracy is measured in percentage (%) and is compared between no landmark, one landmark, and two landmarks. The graph includes bars for 'once' and 'five times' conditions. The chance level is indicated by a horizontal line at 50% accuracy.