RUNNING HEAD: Reorientation to Large-scale Environments

Cue Interaction between Buildings and Street Configurations during Reorientation in Familiar

and Unfamiliar Outdoor Environments

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Abstract

Two experiments investigated how people use buildings and street configurations to reorient in large-scale environments. In immersive virtual environments, participants learned objects' locations in an intersection consisting of four streets. The objects' locations were specified by two cues: a building and/or the street configuration. During the test, participants localized objects with either or both cues. Participants were divided into a competition group and a no-competition group. The competition group learned both cues whereas the no-competition group learned the single cue for trials with single testing cue. For the trials with both testing cues, both groups learned both cues and these two cues were placed at the original locations or displaced relative to each other during testing. Critically, the familiarity with the environment was also manipulated: in Experiment 1, participants learned the same building at the same corner of the same intersection for all trials (familiar); in Experiment 2, participants learned different buildings at different corners of different intersections across trials (unfamiliar). The results showed that the performance in the competition group was impaired in unfamiliar environments but not in familiar environments. When displacement occurred, the participants' preference in unfamiliar environments was determined by the response accuracy of using the two cues respectively, whereas participants in the familiar environment preferred the street configuration with a probability higher than what was solely determined by response accuracy based on individual cues. When the two cues were consistent with each other, they were combined additively in both familiar and unfamiliar environments.

Keywords: reorientation; large-scale environment; familiarity; cue combination; cue competition

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Reorientation is an important behavior for humans and non-human animals. Reorienting in outdoor environments is especially critical for survival. During foraging and homing, wild animals must be able to regain their orientation using trees, rocks or the shape of a river when they are disoriented in a forest. Likewise, humans must be able to regain their orientation using signs, buildings or the configuration of streets when they are disoriented in a city. Although scientists have gained great understandings on reorientation in indoor environments since the study of Cheng (1986), investigation on outdoor reorientation of human adults is rare. The purpose of this study is to examine cue interaction in outdoor reorientation of human adults. Before we further specify the questions of the current study, we will first review the relevant studies examining cue interaction in indoor reorientation. We will then propose a general research procedure to study cue interaction. We will finally frame the questions of the current study by applying the general research procedure to reorientation in outdoor environments.

In a seminal study, Cheng (1986) trained rats to search for food hidden at one of the four corners in a rectangular room with four different panels in the corners. During the test, rats searched for the food after being disoriented. Instead of searching in the correct corner, the rats divided their search between the correct corner and the corner diagonally opposite to the correct corner, which is geometrically equivalent to the correct corner. This result indicated that rats only used the shape of the room to distinguish the geometrically correct corners but did not use the panels to avoid the corner diagonally opposite to the correct corner. Hermer and Spelke (1994, 1996) found that children between 18 and 24 months old were able to use the shape of the room to search for a hidden toy. However, they could not use the featural cues such as the colors

of the walls or distinctive objects to guide their search. Following these pioneer studies, an enormous number of studies examined the relative importance of geometry and features in reorientation (e.g. Brown, Spetch, & Hurd, 2007; Learmonth, Newcombe, & Huttenlocher, 2001; Lee & Spelke, 2010; Twyman, Friedman, & Spetch, 2007; for review, see Cheng, Huttenlocher, & Newcombe, 2013).

There are also studies that contrasted two cues other than geometry and features in reorientation. Recently, several studies contrasted different geometric cues in reorientation. For example, angles of corners in a room were contrasted with the shape of the room (e.g., Lubyk, Dupuis, Gutiérrez, & Spetch, 2012; Sturz, Forloines, & Bodily, 2012). The horizontal shape of a room was contrasted with vertical cues in the room, including tilted floor (e.g., Nardi, Newcombe, & Shipley, 2011) and walls with different heights (Du, Spetch, & Mou, 2016). There are also studies that compared the boundary of an enclosed environment with a single landmark or a landmark array in reorientation (see Lew, 2011, for a review).

Regardless of the types of cues that were contrasted, most of the studies in reorientation examined cue competition either in encoding orientations or in regaining orientations after disorientation. In the former case, studies primarily investigated whether two different cues (e.g. geometry and feature cues) compete for the encoding resources (e.g., Pearce, Graham, Good, Jones, & McGregor, 2006). In the latter case, studies primarily investigated whether people prefer one cue to the other cue when the two cues indicate different orientations (e.g., Ratliff & Newcombe, 2008). However, to our knowledge, studies that examined cue competition in both encoding and retrieving phases in one reorientation experiment are rare. We believe that in order to understand cue competition in reorientation more completely, we should examine cue competition in both encoding and retrieval phases in the same experiment.

Besides cue competition, cue combination is one other important type of cue interaction. In cue combination, people combine estimations indicated by two cues to improve their estimation. Cue combination has been examined in several spatial behaviors including homing (Chen & McNamara, 2014; Chen, McNamara, Kelly, & Wolbers, in press; Legge, Wystrach, Spetch, & Cheng, 2014; Nardini et al., 2008; Zhao & Warren, 2015a) and object localization (Holden, Newcombe, & Shipley, 2013; Huttenlocher, Hedges, & Duncans, 1991; Mou & Spetch, 2013; Sampaio & Wang, 2009). Cue combination is usually illustrated by variance reduction in spatial judgments when both cues are available than when either cue is available (Cheng et al., 2007). However, in a typical reorientation paradigm, reorientation performance is measured in terms of accuracy in choosing the correct location and judgment variance within a participant is usually not available. Therefore, cue combination is rarely examined in reorientation (Xu, Regier, & Newcombe, 2017).

In this study, we propose that to understand cue interaction in reorientation more thoroughly, we should examine both cue competition and cue combination in a single reorientation experiment (Mou & Spetch, 2013). In particular, a standard procedure to study cue interaction in reorientation should, in one single experiment, examine three types of cue interaction: cue competition in encoding orientations, cue combination in retrieving orientations when two cues indicate the same orientation, and cue competition in retrieving orientations when two cues indicate different orientations.

Moreover, to our knowledge, research on cue interaction during reorientation of human adults in an outdoor large-scale environment is rare. In the previous studies with human adults, participants were usually tested in room-size environments. As suggested in previous research, the size of the environment could change the strategies used by human adults in reorientation

(Ratliff & Newcombe, 2008; Sturz & Kelly, 2013). Reorientation to broader outdoor environments (e.g., a city) is indeed a more common spatial task and more critical to survival (Mou et al., 2014). In everyday life, people can visually apprehend the local environment (e.g., a room) from a single viewpoint whereas they have to locomote considerably to apprehend an outdoor large-scale environment (Montello, 1993). Thus, it is much less likely that people lose their orientation in a local environment (i.e. a room) than in an outdoor large-scale environment. Therefore, it is more important to study how human adults reorient in outdoor large-scale environments.

In the current study, human adults regained their orientation in a city after disorientation. We examined two cues: a building in one corner of an intersection of four streets and the configuration of the streets (Figure 1). We acknowledge that there is no clear theoretical motivation to examine cue interaction between a building and a street layout. One may claim that the distinction between a building and a configuration of the streets is an example of the distinction between features and geometries. However, as a building has its own geometrical shape, we do not hold such claim. We chose buildings and street layouts primarily because they are two common cues in a city (Siegel & White, 1975). Following the standard procedure of studying cue competition proposed above, we investigated: (1) whether learning a building and learning a street configuration compete for common cognitive resources during encoding; (2) whether these two cues are additively combined in determining orientation after disorientation when these two cues indicate the same orientation; and (3) how these two cues are preferred after disorientation if they indicate two difference orientations.

We used the overshadowing paradigm to investigate whether learning a building and learning a street layout compete for common cognitive resources during encoding. The

overshadowing paradigm is widely used to investigate the competition between two cues presented simultaneously during learning a response to a stimulus (Pavlov, 1927). Specifically, when Cue A overshadows Cue B, behaviorally the performance of localizing the target is better after individuals learn the target with the presence of only B than after individuals learn the target with the presence of both A and B.

Asymmetrical overshadowing effects, that is, Cue A overshadows Cue B but Cue B does not overshadow Cue A, are used to support Cue A is the dominant cue. For example, some studies showed that an enclosed shape overshadowed a landmark but not vice versa (Doeller & Burgess, 2008; Sovrano, Bisazza, & Vallortigara, 2003; Wall, Botly, Black, & Shettleworth, 2004). Therefore, the enclosed shape was the dominant cue. In contrast, symmetrical overshadowing effects, that is, Cue A and Cue B overshadow each other, are used to support that two cues are equally important. For example, other studies showed that landmarks could also overshadow an enclosed shape (Gray, Bloomfield, Ferrey, Spetch, & Sturdy, 2005; Pearce, Graham, Good, Jones, & McGregor, 2006; Wilson & Alexander, 2008). Therefore, an enclosed shape and a landmark are equally important in these studies. In the current study, asymmetrical overshadowing effects will be interpreted to mean that the overshadowing cue is more dominant over the overshadowed cue; symmetrical overshadowing effects will be interpreted to mean that these two cues compete for the common cognitive resources and are equally important; finally no overshadowing effect will be interpreted to mean that these two cues do not compete for the common cognitive resources.

To test whether the cues of a building and a configuration of streets are additively combined in the retrieval phase of reorientation, we tested whether the cue leading to a more accurate response has a larger contribution to reorientation. Bayesian combination is one

example of additive combination and has been examined in the field of spatial cognition (Chen & McNamara, 2014, Chen et al., in press; Cheng et al., 2007; Mou & Spetch, 2013; Nardini et al., 2008; Zhao & Warren, 2015a). Bayesian combination predicts that two cues are combined additively to reduce the inaccuracy (variance) of estimation; and that the weights of cues are inversely proportional to the relative inaccuracy (variance) using either cue individually. In a typical reorientation study, measurement of variance is not easy. Usually, the reorientation performance was measured in accuracy. In the current study, we proposed an accuracy-based combination model (see detailed specifications in General Method below) and tested whether the cue that leads to a higher response accuracy when being presented alone has a larger contribution to reorientation when both cues are available and indicate a consistent orientation during testing.

In addition, we also investigated how the cues of a building and a configuration of streets are preferred in the retrieval phase of reorientation when they indicate different orientations. In particular, we are interested in investigating whether people prefer a cue that leads to a more accurate reorientation. Ratliff and Newcombe (2008) used a conflicting cue paradigm to examine cue preference in indoor reorientation. In their experiment, participants learned the location of a hidden target with respect to both featural and geometric cues in a large rectangular room or in a small rectangular room. Then, participants were tested with the featural cue being moved to one adjacent wall so that there was a conflict between the featural cue and the geometric cue. The results showed that participants in a large room were more likely to choose the corner indicated by the featural cue, while participants in a small room were more likely to choose the corner indicated by the geometric cue. The authors claimed that human adults gave more weight to the cue that was more salient, assuming the geometric cue is more salient in a small room and the featural cue is more salient in a large room. In the current study,

we also used the conflicting cue paradigm. We tested whether the cue that leads to a higher response accuracy when being presented alone has a larger contribution to reorientation when both cues are available but indicate conflicting orientations during testing.

Most importantly, we hypothesized that the interactions, especially competition in encoding and combination in retrieval, between the building and the street configuration are modulated by the degree of participants' familiarity with the city. This hypothesis is based on the following speculations: the more familiar with an environment, the more likely people encode the spatial relations between buildings and street configurations; whether people encode the spatial relations between buildings and street configurations or not will modulate cue competition during encoding and retrieval of orientations.

A mental representation of the spatial relations between buildings and street configurations might reduce the cue competition in encoding orientations. There are at least two possible mechanisms for such reduction. First, people who have encoded the relations between the two cues may easily find the other cue when they see one cue. Such cue facilitation may counterbalance the cue competition for the common cognitive resource in encoding orientations relative to individual cues. Second, people may also encode the spatial relations between buildings and street configurations as well as their orientations relative to individual cues. Because encoding the spatial relations between buildings and street configurations consumes cognitive resources, fewer cognitive resources are left for encoding orientations in terms of each individual cue, producing cue competition. Therefore, cue competition is smaller for people who have already encoded the relations between buildings and street configurations[1]. Note that we do

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[1] We grateful to one anonymous reviewer for the suggestion of the second mechanism.

not distinguish between these two mechanisms empirically in the current study. As speculated above, as people become more familiar with an environment, they are more likely to encode the spatial relations between buildings and street configurations. Therefore, the effect of cue competition in encoding orientations is reduced or eliminated in a familiar environment but not in a novel environment.

A mental representation of the relations between buildings and street configurations might modulate cue preference during the retrieval phase when these two cue indicate different orientations. People who have not encoded the relations between two cues should not be able to detect the relative displacement between these two cues. Therefore, they may combine estimates based on each cue by giving more weight to the cue producing a more accurate response, assuming that people can know which cue results in a more accurate response similar to the assumption that people know which cue results in a more variable response in the cue combination literature (Chen & McNamara, 2014; Cheng et al., 2007; Mou & Spetch, 2013; Nardini et al., 2008; Zhao & Warren, 2015a). In contrast, people who have encoded the relations between two cues should be able to detect the relative displacement between the two cues. Therefore, cue preference may be affected not only by the response accuracy based on individual cues but also by other cognitive factors including participants' belief of the stability of cues. A cue resulting in a more accurate response might not be the cue that participants believe to be more stable, just as a cue resulting in less variable response might not be perceived to be more stable (Etienne & Jeffery, 2004; Foo et al., 2005; Zhao & Warren, 2015b). Therefore, in a novel environment, cue preference in the retrieval phase of reorientation is determined by response accuracy using individual cues whereas in a familiar environment, cue preference in the retrieval

phase of reorientation may also be affected by people's belief of cue stability. Note that no prior theory can predict which cue, a building or a street configuration, is more stable.

In summary, the purpose of the current study was to examine cue interaction between a building and a street configuration in reorientations in a large-scale environment, more specifically, cue competition during encoding orientations, and cue combination and cue competition in retrieval of orientation. Furthermore, we investigated whether the cue competition between a building and a street configuration in reorientation, both during encoding and retrieval, are modulated by people's familiarity with the environment.

General Method

Two experiments were conducted to examine cue interaction between a building and a street configuration. These two experiments were identical except that Experiment 1 used a familiar environment, whereas Experiment 2 used an unfamiliar environment. The method to manipulate the familiarity will be discussed in each experiment. Here, we describe the common materials, design, procedure, and the method of data analyses.

Materials and Design

The experiments were conducted in a physical room that was 4m by 4m. A swivel chair was placed in the middle of the room. A virtual environment was displayed in stereo with an nVisor SX60 head-mounted display (HMD) (NVIS, Inc. Virginia). Each participant was placed in an InterSense IS-900 motion tracking system (InterSense, Inc., Massachusetts) so that participants could look around in the virtual environment. The virtual environment was a city consisting of four streets and a building as well as three identical trees (Figure 1). Each participant had 16 trials, each consisting of a learning phase and a testing phase. In the learning

phase of each trial, participants learned the location of four objects (lock, candle, wood, and bottle, all fitting within approximate 50cm) that were located at the end of each street respectively. In the testing phase of each trial, participants were required to locate two of the four objects. The locations of the objects differed across trials as in a working memory paradigm (Cheng, 1986).

Participants could rely on two kinds of cues to locate the objects: the building and the configuration of the streets (Figure 1). When there was a building cue, the building was located at one of the corners of the intersection. At the other three corners were three identical trees. When there was no building cue, the building was substituted by a tree identical to those at the other three corners. When there was a street configuration cue, the street configuration consisted of two short streets and two long streets. The streets were surrounded by walls that were 5m tall. Like the building, the street configuration cues in the current research could also be used to identify all four streets because each of the streets had one adjacent street with the same length and one with a different length, producing an asymmetric or a one-fold rotationally symmetric environment (Kelly et al., 2008). When there was no street configuration cue, the streets described above were substituted by four identical streets, the total length of which is equal to that of the original streets.

The experimental design was comprised of a combination of learning cue groups and different testing cue types (Figure 2). The learning cue group was manipulated between participants with two conditions: A competition group in which both the building and the street configuration cue were presented during learning and a no-competition group in which the type of cues presented during learning was the same as that presented during testing. The testing cue type was manipulated within participants with four conditions: B-test-trials in which only the

building cue was presented during testing, S-test-trials in which only the street configuration cue was presented during testing, SB-test-trials in which both cues were presented during testing, and Conflict-test-trials in which both cues were presented during testing but the building and the street configuration were displaced relative to each other to indicate a conflicting orientation. Note that in the Conflict-test-trials, the building and the street configuration were displaced such that the response street indicated by the building and the response street indicated by the street configuration had the same length to prevent participants from using one single street length as a cue (see Figure 2).

More specifically, in the competition group, the learning cues were always SB, and the testing cues could be S, B, SB, or conflicting SB. In the no-competition group, the learning cues could be S, B, or SB, and the testing cues were the same as the learning cue (S, B, or SB), except that in the Conflict-test-trials, the learning cues were SB and the testing cues were conflicting SB. The learning cue groups were so named because on the S-test-trials and the B-test-trials, participants in the competition group learned two cues that might compete with each other, but participants in the no-competition group only learned a single cue removing the potential competition. The distinction between competition and no-competition is nominal for the SB-test-trials.

Participants were randomly assigned to the two groups subject to the constraint that there were an equal number of males and females in each group. There were 16 trials for each participant. The first twelve trials were randomly assigned to the B-test-, S-test-, and SB-test-trials, four trials for each. The last four trials were the Conflict-test-trials. The reason the Conflict-test-trials were last was that participants may have decided that the cues were unreliable

if they found the cues were in conflict, and this might have affected their performance in the other conditions in an unpredictable way.

For the test phase of each trial, participants judged the locations of two objects. Specifically, they localized the first and third objects that they had learned. It is important to note that these two objects were originally located at the opposite streets so that the two target streets were different in terms of street length (short vs. long) and their angular distance with the building (closer vs. farther). For each target object, participants chose between the correct street and one distracting street. In all types of trials, the distracting street and the correct street had the same length. In the B-test-trials, in which all four streets during testing had the same length, the distracting street and the correct street had the same angular distance with the building (i.e., both closer to or both farther away from the building).

Procedure

Wearing a blindfold, participants were guided into the testing room and seated on the swivel chair. Participants donned the HMD and then removed the blindfold. Participants were instructed to pretend to be passengers who would travel a city in a car. Participants were always passively transported. They never physically locomoted during transportation but they could physically turn their head to have a viewpoint different from their travelling direction.

In the learning phase of each trial, participants were transported at a constant speed (10 m/s for translation and 45°/s for rotation) from the center of the intersection to the end of each street. Fog was placed in front of participants with a distance (15 meters) so that participants could not see the ends of streets when they stood at the intersection. If participants could have seen the ends of the streets at the intersection, they might have easily identified all objects

without any navigation. At the end of each street they could see an object and were instructed to learn its location. Then they were transported back to the center of the intersection before visiting the next object at the end of the adjacent street (clockwise or counter-clockwise). The first object that they visited and the learning order (clockwise or counter-clockwise) were randomized. Participants' initial orientation was aligned with their travelling direction. Participants could look around during their movement.

After all objects were visited once, all objects were removed and the screen turned black for two seconds. Then the testing phase started. No fog was placed to block participants' view of either the street configuration or the building. The specific cues (the street configuration, the building or both) were presented. Participants were released at the center of the intersection with a random orientation. An object was shown at the right bottom corner of the screen and participants were instructed to choose the correct street for that object using a mouse. They were only allowed to choose between two streets (the correct and the distracting ones). One street was indicated by a green arrow and the other one was indicated by a red arrow. Whether the correct street was indicated by the red or the green arrow was randomized. Participants were asked to click the left mouse button if they chose the street indicated by the red arrow or click the right mouse button if they chose the street indicated by the green arrow. After participants' response, the screen turned black for two seconds. Participants were then released at the center of the intersection with a random orientation and were asked to choose the correct street for the second object. After they had responded for both objects, the screen turned black for two seconds and the next trial began. Participants' responses for both target objects were recorded for each trial.

Competition during Encoding

To examine the competition between street configurations and buildings during encoding, we contrasted the competition group with the no-competition group in terms of the accuracy in targets' localization in the B-test-trials and the S-test-trials. Participants in the competition group learned the objects' locations in the presence of both the building and the street configuration, whereas participants in the no-competition group learned the objects' locations in the presence of either the building or the street configuration. If learning the building overshadowed learning the street configuration, then the competition group would perform worse than the no-competition group on the S-test-trials. If learning the street configuration overshadowed learning the building, then the competition group would perform worse on the B-test-trials. If those two cues did not compete with each other, the performance of the competition group and the no-competition group would be comparable on both the B-test-trials and the S-test-trials.

We examine cue interaction during retrieval when the two cues indicated the same orientation and when the two cues indicated different orientations. Below we referred to the former one as Combination during Retrieval and the latter one as Competition during Retrieval. Note that we only examined interaction (combination and competition) during retrieval for the competition group, but not for the no-competition group because the learning conditions in the SB-, S-, and B-test-trials were different in the no-competition group (Mou & Spetch, 2013).

Combination during Retrieval

To examine the combination of cues during retrieval, we contrasted the performance in target localization in the SB-test-trials with the sum of performance in the S-test-trials and in the B-test-trials. If the two cues are combined additively, the performance in the SB-test-trials should be comparable to the sum of the performances in the S-test-trials and in the B-test-trials.

Note that a combination model based on variance (e.g. Bayesian combination model reviewed by Cheng et al., 2007) cannot be applied to the current reorientation paradigm because of the nature of the data in the current study. It is difficult to obtain variance in reorientation studies because they usually collect categorical data instead of continuous data.

An accuracy-based combination model. Instead of using variance-based combination models, we developed a combination model based on accuracy, which is the probability of making the correct response. We defined the participants' ability to select the correct response from the alternative response with the presence of valid cues in terms of the logit of the response accuracy. The logit of a probability, p, is defined as logit $(p) = \log (p/(1-p))$. Logit is widely used in modeling binary data. One important advantage of using the logit of accuracy instead of accuracy itself is to address the ceiling effects when accuracies are combined. Specifically, accuracy cannot be larger than 1. The sum of accuracies of S-test-trials and of B-test-trials, however, will be larger than 1 when both cues respectively lead to an accuracy above chance level (i.e. 0.5 as participants chose between two locations). Because the logit can be any real number, it has no ceiling restriction and can be used to model the combination of cues.

The accuracy of localizing the target with the building cue alone is denoted by A_B. The accuracy of localizing the target with the street configuration cue alone is denoted by A_S. The accuracy of localizing the target with both cues is denoted as A_{SB}. If the ability of choosing the correct response due to a single cue (i.e. the building or the street configuration) can be additively combined, then

$$logit\ (A_{SB}) = logit\ (A_S) + \ logit\ (A_B) \tag{1}$$

Based on the definition of logit, Equation 1 can also be written as:

$$\frac{A_{SB}}{(1 - A_{SB})} = \frac{A_S}{(1 - A_S)} * \frac{A_B}{(1 - A_B)}$$

Therefore, we obtain

$$A_{SB} = \frac{A_S * A_B}{A_S * A_B + (1 - A_S) * (1 - A_B)} \tag{2}$$

Equations 1 and 2 can also be derived from the method described in McClelland (1991, p. 7-8; see also Twilley & Dixon, 2000). (More details are provided in the Appendix.) We contrasted the estimated A_{SB}, which was calculated based on the observed A_S and A_B according to Equation 2, with the observed A_{SB} to test whether cue combination can be estimated by the proposed accuracy-based combination model.

Competition during Retrieval

To investigate the competition between buildings and street configurations during retrieval, we examined the cue preference in the Conflict trials (see Figure 2). In each trial, the building was displaced with respect to the street configuration to indicate a conflicting orientation. Participants were then forced to choose between the response indicated by the street configuration (e.g. X in Figure 2) and the response indicated by the building (e.g. Y in Figure 2).

In the Conflict-test-trials, the tendency to select the response indicated by one cue is compromised by the tendency to select the response indicated by the other cue. Therefore, the probability of choosing the response indicated by one cue (e.g. the street configuration) should be determined by subtracting the tendency to select the response indicated by the other cue (e.g. the building) from the tendency to select the response indicated by this cue (e.g. the street configuration).

We denote the probability of choosing the response indicated by the street configuration in the Conflict-test-trials as $P_{S|Conflict}$[2]. Formally, we produce the following equation:

$$logit\left(P_{S|Conflict}\right) = logit\left(A_S\right) - logit\left(A_B\right) \qquad (3)$$

Based on the definition of Logit, Equation 3 can also be written as:

$$\frac{P_{S|Conflict}}{1 - P_{S|Conflict}} = \frac{A_{SB}}{1 - A_S} * \frac{1 - A_B}{A_B}$$

Therefore, we obtain:

$$P_{S|Conflict} = \frac{A_{S}*(1-A_B)}{A_{S}*(1-A_B)+(1-A_S)*A_B} \qquad (4)$$

We can derive Equation 4 from Equation 2 directly as well. Participants were forced to choose between the response indicated by the street configuration (e.g. X in Figure 2) and the response indicated by the building (e.g. Y in Figure 2). The probability of choosing response X using the street configuration cue is still the accuracy in the S-test-trials, i.e. A_S. The probability of choosing response X with the displaced building is the error rate in the B-test-trials, i.e. $1-A_B$. Replacing A_B with $1-A_B$ in Equation 2, we still obtain Equation 4.

We contrasted the estimated (or predicted) $P_{S|Conflict}$, which was calculated based on the observed A_S and A_B according to Equation 4, with the observed $P_{S|Conflict}$ in the Conflict trials to test whether cue competition in the Conflict-test-trials can be estimated by the proposed accuracy-based combination model. If the observed $P_{S|Conflict}$ was comparable to the predicted

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[2] Whether we use probability of choosing the response indicated by the street configuration or indicated by the building did not rely on any assumption about cue stability and should not affect the conclusions about cue preference. We just arbitrarily chose the former one to examine cue preference.

$P_{S|Conflict}$, then we would conclude that the cue preference was solely determined by the response accuracy based on individual cues. If the observed $P_{S|Conflict}$ was larger than the predicted $P_{S|Conflict}$, then we would conclude that participants preferred the street configuration more than the preference that is solely determined by the response accuracy using individual cues and the additional preference occurred because participants believed that the street configuration was more stable than the building. If the observed $P_{S|Conflict}$ was smaller than the predicted $P_{S|Conflict}$, then we would conclude that participants preferred the street configuration less than the preference that is solely determined by the response accuracy using individual cues and the lower preference for the street configuration occurred because participants believed that the street was less stable than the building.

Experiment 1

The purpose of Experiment 1 was to investigate cue interactions between a building and a street configuration during reorientation in a familiar environment. Participants learned the locations of four objects in an intersection consisting of a building and four streets (Figure 1). The same building was placed on the same corner of the same layout of streets across trials, allowing participants to become familiar with that environment.

We hypothesized that, in a familiar environment, participants encoded the relations between the building and the street configuration. The represented relations between the building and the street configuration could reduce the competition between these two cues during encoding. The represented relations between the building and the street configuration could also be used to detect the relative displacement between the building and the street configuration. Therefore, participants might choose the cue that they believed to be more stable with a probability higher than what is solely determined by response accuracy using individual cues.

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. In addition to the materials, design, and procedure described in the General Method above, the appearance of the building and the street configuration were the same across the learning phases of all the 16 trials. The relationship between the building and the street configuration were also constant across all the trials: the building was always located between the two short streets. The building was approximately 10m long, 10m wide and 50m tall. The street configuration consisted of two long streets (50m each) and two short streets (25m each). When there was no street configuration cue, the street configuration cue was substituted by four 37.5 meters-long identical streets.

Results and Discussion

      Competition during encoding. Figure 3 plots the mean accuracy as a function of testing cue type (S-, B-, SB-test-trials) and learning cue group (competition or no-competition). Accuracy was computed for each participant and each testing cue type condition (S-, B-, SB-test-trials), and analyzed in mixed-model analyses of variance (ANOVAs), with variables corresponding to testing cue type (within participants) and learning cue group (between participants).

      The main effect of testing cue type was significant, $F(2,188) = 6.06$, $p < .01$, $MSE = 0.026$, $\eta_p^2 = 0.06$. The main effect of learning cue group was not significant, $F(1,94) = 0.17$, $p = 0.68$, $MSE = 0.072$, $\eta_p^2 = 0.002$. The interaction between testing cue type and learning cue group was not significant, $F(2,188) = 0.40$, $p = 0.67$, $MSE = 0.026$, $\eta_p^2 = 0.004$. The null effect of learning cue group and the null interaction between testing cue type and learning cue group

suggest that learning the buildings and learning the street configurations did not compete with each other.

The performance in the S-test-trials was significantly worse than that in the SB-test-trials ($t(188) = 3.47, p < .001$). The performance in the B-test-trial was significantly different from that in the S-test-trials ($t(188) = 2.01, p = 0.04$)[3] but was not different from the SB-test-trials ($t(188) = 1.45, p = 0.15$). The result shows that reorientation using the building was more accurate than using the street configuration. The accuracy in all six conditions (combinations of the two independent variables) was above chance level ($ts(47) > 2.78, ps < .01$).

Combination during retrieval. Equation 2 was used to test whether these two cues were additively combined in the SB-test-trials in the competition group. The estimated A_{SB} was computed for each participant using Equation 2. The means of the estimated A_{SB} and of the observed A_{SB} across participants are plotted in Figure 4. They were not significantly different from each other ($t(47) = 0.02, p = 0.98$). This result was consistent with the conclusion that those two cues were combined additively during testing.

Competition during retrieval. Equation 4 was used to investigate whether participants preferred cues solely according to response accuracy based on individual cues in the Conflict-test-trials. The means of the observed $P_{S|Conflict}$ and the estimated $P_{S|Conflict}$ based on Equation 4 across participants are plotted in Figure 5. The former was significantly larger than the latter (($t(47) = 2.96, p < .01$). Therefore, the percentage of actually choosing the street indicated by the street configuration was significantly higher than what was estimated based on the relative

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[3] There are different approaches of post-hoc comparison including Fisher's LSD test and the Bonferroni correction. We used Fisher's LSD test to conduct the post-hoc comparison and let readers decide how to interpret the statistical results. The Bonferroni correction can be implemented by using an alpha of .05/3 in this case.

response accuracy using each cue. This result suggested that participants might have believed that the street configuration was more stable than the building, consistent with our speculation that a larger item is believed to be more stable.

Experiment 2

The purpose of Experiment 2 was to investigate the interactions of buildings and street configurations during reorientation in an unfamiliar environment. Unlike Experiment 1, in which we used the same building and set of streets across trials, we used 16 different combinations of four different buildings and four sets of streets in Experiment 2. As the environment (i.e., the combination between buildings and street configurations) changed from trial to trial, participants experienced a novel environment on every trial.

We hypothesized that, in an unfamiliar environment, participants would not accurately encode the relations between the building and the street configuration. Hence, no mental representation of the spatial relations between the building and the street configuration could be used to reduce the competition between these two cues during encoding. Consequently, cue competition between these two cues during encoding was expected to be observed. Similarly, no represented spatial relations between the building and the street configuration could be used to detect the relative displacement between the street configuration and the building. Therefore, participants' preference of cues was totally determined by the relative response accuracy using each cue during the test in the Conflict-test-trials.

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 material and design in Experiment 2 was the same as in Experiment 1 except for the following change. In Experiment 2, the virtual environment in each trial was novel. We used four different buildings and four street configurations with different length ratios of the short street to the long street (1:2, 1:2.5, 1:3, and 1:3.5) keeping the sum of the short and long streets the same as 75 meters (25:50, 21:54, 19:56, and 17:58). Thus, we created 16 different environments (combinations of four buildings and four street configurations). We assigned each environment to one of the 16 trials so that environments in all the 16 trials were different. Furthermore, the location of the building with respect to the streets was randomized for each configuration. The 16 environments were randomly assigned into the four types of trials with the restriction that each length ratio was used once in each type of trials.

Results and Discussion

Competition during encoding. Mean accuracy as a function of testing cue type (S-, B-, SB-test-trials) and learning cue group is plotted in Figure 6. Accuracy was computed for each participant and each testing cue type condition (S-, B-, SB-test-trials) and analyzed in mixed-model analyses of variance (ANOVAs), with variables corresponding to testing cue type (within participants) and learning cue group (between participants).

The main effect of testing cue type was significant, $F(2,188) = 3.61$, $p < .05$, $MSE = 0.035$, $\eta_p^2 = 0.04$. The main effect of learning cue group was significant, $F(1,94) = 5.20$, $p < .05$, $MSE = 0.05$, $\eta_p^2 = 0.05$. The interaction between testing cue type and learning cue group was not significant, $F(2,188) = 0.80$, $p = 0.45$, $MSE = 0.035$, $\eta_p^2 = 0.008$. The effect of learning cue group together with the null interaction between testing cue type and learning cue group indicates that learning the buildings and learning the street configurations competed with each other during encoding. The null interaction between testing cue type and learning cue group

might indicate that the overshadowing effects carried over to the SB-test-trials although SB-test-trials were the same in these two groups. Another explanation is that participants in the competition group could not predict whether both cues were available during test but those in the no-competition group could in the testing phase of the SB-test-trials.

The difference between the performance in the S-test-trials and that in the B-test-trials was not significant ($t(188) = 1.01$, $p = 0.31$). The difference between the performance in the B-test-trials and that in the SB-test-trials was not significant ($t(188) = 1.64$, $p = 0.10$). The performance in the S-test-trials was significantly worse than that in the SB-test-trials ($t(188) = 2.65$, $p = .008$). The accuracy in all six conditions (combinations of the two independent variables) was above the level of chance, i.e.0.5 ($ts(47) > 2.10$, $ps < .05$).

Combination during retrieval. Equation 2 was used to test whether these two cues were additively combined in the SB-test-trials in the competition group. The means of the estimated A_{SB} and of the observed A_{SB} across participants are plotted in Figure 7. They were not significantly different from each other ($t(47) = 0.56$, $p = 0.58$). This result indicated that those two cues were combined additively during testing.

Competition during Retrieval. Equation 4 was used to investigate whether participants preferred cues solely according to response accuracy based on individual cues in the Conflict trials. Figure 8 plots the mean of the $P_{S|Conflict}$ estimated based on Equation 4 and the observed $P_{S|Conflict}$ across participants. The former was not significantly different from the latter ($t(47) = 0.85$, $p = 0.40$). This result suggested that the percentage of actually choosing the location indicated by the street configuration was comparable to what was estimated based on the relative response accuracy based on each cue alone.

Model Fit

The results of both experiments showed that the estimated A_{SB} and the observed A_{SB} were comparable. Therefore, we concluded that both experiments showed that these two cues were combined additively during testing when these two cues indicated the same response. We acknowledge that this conclusion is based on the null effect of contrasting the estimated A_{SB} and the observed A_{SB}. In order to strengthen the evidence for the additive combination of cues, we compared three different models of the results from S-test-trials, B-test-trials, and SB-test-trials in the competition groups. Because both experiments showed the null effect, we combined the data from the two experiments.

In the additive model, we assumed that performance (in terms of log odds accuracy or logit) was based on the response strength for street configurations and the response strength for the buildings. In particular, $\text{logit}(A_S) = R_S$, $\text{logit}(A_B) = R_B$, and $\text{logit}(A_{SB}) = R_S + R_B$. In a full model, we assumed that performance in the SB-test-trials was unconstrained; thus, log odds accuracy would be determined by a separate response strength parameter in each testing cue type. In particular, $\text{logit}(A_S) = R_S$, $\text{logit}(A_B) = R_B$, and $\text{logit}(A_{SB}) = R_{SB}$. Finally, we also considered a model in which participants simply selected the best cue for the SB-test-trials, which, in these experiments, was the building. In this case, $\text{logit}(A_S) = R_S$, $\text{logit}(A_B) = R_B$, and $\text{logit}(A_{SB}) = R_B$.

The models were fit by maximizing the likelihood of the data using the generalized linear modeling program glmer (Bates, Maechler, Bolker, & Walker, 2014) in the statistical environment R (R Core Team, 2015). The fits were compared using the Bayesian Information Criterion (BIC), a common model comparison criterion. The BIC values for the three models were as follows: additive, 1075.0; full, 1080.1; and best cue, 1079.0. By this criterion, the

additive model is clearly better than the other two. Following the suggestion of Wagenmakers (2007), the difference in BIC values (ΔBIC) can be converted to an approximation of the Bayes factor, ln(Bayes factor) = ΔBIC/2 . Using this approximation, the Bayes factor for the additive model relative to the full model is 12.81. The Bayes factor for the additive model relative to the best cue model is 7.39. Typically, these values would be interpreted as positive evidence for the additive model relative to the other two.

General Discussion

This project examined the cue interactions between a building and a street configuration during human adult reorientation in familiar or unfamiliar large-scale environments. There are three important findings: 1) Learning the building and learning the street configuration did not compete with each other in the familiar environment but competed with each other in unfamiliar environments; 2) when the building and the street configuration indicated a consistent orientation during testing, participants additively combined the two cues in both familiar and unfamiliar environments; 3) when the building and the street configuration were displaced relative to each other to indicate a conflicting orientation, participants' cue preference in unfamiliar environments was determined by response accuracy in using these two cues respectively, whereas participants in the familiar environment preferred the street configuration with a probability higher than what was solely based on response accuracy provided by individual cues (equivalently, preferred the building with a probability lower than what was solely based on the response accuracy based on individual cues).

The first finding was based on the contrast between the competition group and the no-competition group. Participants in the competition group saw compound learning cues but a single testing cue, whereas participants in the no-competition group saw the same single cue

during learning and testing (the S-test-trials and the B-test-trials in Figure 2). Therefore, impaired performance in the competition group would indicate that during the encoding phase, the unused cue, which was presented during learning but removed during testing, overshadowed the used cue, which was presented during both learning and testing. In the familiar environment (Experiment 1), no impaired performance in the competition group was observed (Figure 3), indicating that learning the building and learning the street configuration did not overshadow each other. In contrast, in unfamiliar environments (Experiment 2), impaired performance in the competition group was observed whether the single testing cue was the building or the street configuration (S-test-trials and B-test-trials in Figure 6), indicating that learning the building and learning the street configuration overshadowed each other.

This finding suggests the familiarity with the environment can affect the competition between buildings and street configurations during encoding. We speculate that the absence of overshadowing in a familiar environment (Experiment 1) might be due to participants' representing the spatial relationship between the building and the street configuration. There are two possible mechanisms in which the represented spatial relation could have reduced or eliminated the overshadowing effect. First, the encoding of the targets' locations in terms of one cue might have facilitated encoding the targets' locations in terms of the other cue. This facilitative effect might have counterbalanced the overshadowing effect, leading to the null overshadowing effect in the familiar environment. Second, as participants had encoded spatial relations between the building and the street configuration, the cognitive resources that were required to encode spatial relations between the building and the street configuration could have been released. Therefore, participants could have extra cognitive resources to encode their orientation relative to individual cues, reducing or eliminating the cue competition. In the

unfamiliar environments, participants might not have encoded the relationship between the building and the street configuration. Therefore, neither mechanisms described above could be used to reduce cue competition. As a result, the overshadowing effect occurred in the unfamiliar environments.

We acknowledge that the early trials in the familiar environment (Experiment 1) might indeed be trials in a novel environment. We removed the first trial of the S-test-trials, the B-test-trials, and the SB-test-trials respectively and only analyzed the other three trials of the S-test-trials, the B-test-trials, and the SB-test-trials in Experiment 1. The same null overshadowing effect was observed (mean accuracy listed in Table 1).

The second finding of the current study was that in both familiar and unfamiliar environments, participants additively combined the buildings and the street configurations during judgment. In both experiments, the performance with two consistent testing cues (in the SB-test-trials) was estimated by the accuracy-based combination model. In particular, logit (A_{SB}) was equal to the sum of logit(A_S) and logit(A_B). Logit of accuracy reflects the ability to distinguish the correct response from the distractor. These results indicated that participants additively combined two individual cues when these two cues indicated the same estimation. This finding is important as it is the first direct empirical indication that two reorientation cues are additively combined during testing. Xu, Regier, and Newcombe (2017) fit a cue combination model with existing empirical data in indoor reorientation, using response accuracy. In their model fit, the response accuracy based on single cue was not empirically obtained but estimated based on their models.

Furthermore, this finding demonstrates a way of examining cue combination using accuracy instead of variance (or standard deviation) of responses. Recently, there has been

increasing interest in examining a Bayesian combination in human spatial cognition (Chen &

McNamara, 2014; Chen et al., in press; Cheng et al., 2007; Legge et al., 2014; Mou & Spetch,

2013; Nardini et al., 2008; Zhao & Warren, 2015a; see also Huttenlocher et al., 1991). Generally,

when a Bayesian combination is analyzed, the variance (or standard deviation) of responses is

used. However, in studying human reorientation, the variance (or standard deviation) of

responses is hard to observe because participants' responses are usually categorical rather than

continuous. Because the method used in the current study examines cue combination using

accuracy (Equations 1 and 2, see also McClelland, 1991), we believe this method provides a

powerful tool to study cue combination when participants' responses are categorical rather than

continuous. (See alternative methods in Mou & Spetch, 2013; Xu, Regier, & Newcombe, 2017.)

We tested the accuracy-based combination model using a recent published study of human

indoor reorientation (Du, Spetch, & Spetch, 2016), which is one of few studies that had all

requisite conditions (two single cue conditions, both cues condition, and conflict cues

condition)[4]. Table 2 summarizes the observed response accuracy in each single cue and both

cues condition, and cue preference in the conflict cue condition. The predictions in the both cues

and conflict cue conditions based on the accuracy-based combination model are also listed.

Clearly, the predicted and observed responses are quite close.

The third finding of the current study was that when the buildings and the street

configurations were in conflict, participants in the unfamiliar environments preferred the cue

according to the response accuracy of using individual cues alone, whereas participants in the

familiar environment preferred the street configurations with a probability higher than what was

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[4] We are grateful to one anonymous for the suggestion to apply our model to other published
studies.

predicted by the relative response accuracy using individual cues. As we hypothesized, participants in an unfamiliar environment might not have encoded the spatial relations between the buildings and the street configurations. Without such encoding, they might not have detected changes in the spatial relations between these two cues during the testing phase of the conflicting trials. Therefore, they preferred cues based on response accuracy in the single cue trials.

In contrast, participants in the familiar environment might have encoded the spatial relations between the building and the street configuration. Therefore, they might have detected changes in the spatial relations between these two cues during the testing phase of the conflicting trials. Hence, the cue preference was not only determined by the response accuracy using individual cues but also affected by participants' belief on cue stability (Zhao & Warren, 2015b). The higher preference on the street configuration than what was predicted by response accuracy suggested that participants might have believed that the street configuration was more stable, which is consistent with our speculation that a larger item (i.e. the street configuration) seems more stable.

It is important to note that in the current study, we conjectured that cue stability might affect cue preference in the Conflict-test-trials in the familiar environment. However, we did not directly manipulate the relative stability of the cues. The relative stability of the cues was presumably constant across our manipulations within and between experiments. In the familiar environment (Experiment 1), both the streets and the buildings appeared the same in the learning phases of all the trials in the competition group. Both the street configurations and the buildings changed their appearance, in particular ratio change for street length and disappearing of buildings, in the testing phases of only the single cue trials (B- or S-test-trials) in the competition group. In Experiment 2, in addition to the appearance changes across learning and testing phases

like in Experiment 1, both the street configurations and the buildings also varied across different trials, in particular four different configurations associated with four different buildings. Therefore, we did not purposely increase the relative stability of the street configuration in the familiar environments or decrease the relative stability of the street configuration cues in the unfamiliar environments. Future research is needed to directly manipulate cue stability and test whether the discrepancy in cue preference between familiar and unfamiliar environments was really caused by participants' belief of cue stability.

To explain both the null overshadowing effect and the additive cue effects in the familiar environment (Experiment 1), we speculate that participants should have encoded the spatial relations between cues as well as the spatial relations between individual cues and the targets. But could these findings be interpreted by a gestalt-type representation of the environment? In a gestalt-type representation, every target is encoded with respect to the entire environment; there is no independent representation of the relations between the target and any individual cues in the environment. Mou and Spetch (2013, Experiment 5) demonstrated that if participants developed a gestalt-type representation of an array of objects (a shape formed by cue objects and the target object), there were both overshadowing effects and super-additive cue effects. These demonstrations suggest that the findings of Experiment 1 may not be explained by a gestalt-type representation of the environment. We note that we cannot exclude that possibility that people develop a gestalt-type representation if they overlearn an environment.

All these findings support our proposal that in studying cue interaction, we should examine cue competition during both encoding and retrieval phases and cue combination in the retrieval phase. Whether we study cue competition in the encoding or in the retrieval phases may change our conclusion on relative importance of cues. For example, the null overshadowing

effect in Experiment 1 indicated that neither the building nor the street configuration were more important in using cognitive resources during encoding orientation in terms of cues. Otherwise, one may overshadow the other one. However, participants in the same experiment preferred the street configuration in the retrieval phase when these two cues indicated different orientations, indicating that the street configuration might be dominant in the retrieval phase. In addition, whether we study cue competition or cue combination in the retrieval phase might also change our conclusion on cue importance. For example, in Experiment 1, participants additively combined the cues of the building and the street configuration when they indicated the same orientation, which suggested that the building (the cue producing more accurate responses) had a larger contribution to the combined estimation. However, when these two cues indicated different orientations, participants preferred the street configuration cue over the building cue. Hence, it is important to examine all these three types of cue interaction in the same experiment in order to get an accurate picture of cue interaction in all spatial behaviors.

Most importantly, the findings of the current study indicate that familiarity with the environment modulated cue competition in encoding and retrieving the orientations. These findings suggest that we should consider the role of familiarity with the environment when we study cue interaction during reorientation or in other spatial tasks.

Appendix

Proof of

$$A_{SB} = \frac{A_S * A_B}{A_S * A_B + (1 - A_S) * (1 - A_B)}$$

We assume that each of the two responses can be characterized by response strength. Using the

Luce (1963) choice model, the probability of being correct, *A*, and incorrect, *1 - A,* would be:

$$A = \frac{X}{X + Y}$$

$$1 - A = \frac{Y}{X + Y}$$

where *X* and *Y* are the response strengths for the correct and incorrect response. McClelland

(1991) argued (following Morton, 1969; see also Ashby & Townsend, 1986) that the response

strengths for independent cues should multiply. Thus, $X_{SB} = X_S X_B$ and $Y_{SB} = Y_S Y_B$ where X_{SB} and

Y_{SB} are the response strengths when both street configuration and building are available, X_S and

Y_S are the response strengths when only the street configuration is available, and X_B and Y_B are

the response strengths when only the building is available. Algebraic manipulation yields:

$$A_{SB} = \frac{X_{SB}}{X_{SB} + Y_{SB}} = \frac{X_S X_B}{X_S X_B + Y_S Y_B} = \frac{\frac{X_S X_B}{(X_S+Y_S)(X_B+Y_B)}}{\frac{X_S X_B}{(X_S+Y_S)(X_B+Y_B)} + \frac{Y_S Y_B}{(X_S+Y_S)(X_B+Y_B)}}$$

$$= \frac{\frac{X_S}{(X_S+Y_S)} * \frac{X_B}{(X_B+Y_B)}}{\frac{X_S}{(X_S+Y_S)} * \frac{X_B}{(X_B+Y_B)} + \frac{Y_S}{(X_S+Y_S)} * \frac{Y_B}{(X_B+Y_B)}}$$

$$= \frac{A_S * A_B}{A_S * A_B + (1 - A_S) * (1 - A_B)}$$

Acknowledgments

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Table Captions

Table 1

Observed mean accuracy as a function of testing cue type (S, B, SB) and competition group with and without removing the first trial in each testing cue type.

	All trials			Without first trials		
	S	B	SB	S	B	SB
No-competition	0.62	0.65	0.69	0.62	0.64	0.68
Competition	0.59	0.65	0.68	0.61	0.64	0.69

Table 2

Observed mean accuracy in single cue and both cues condition, and mean cue preference in the conflict cue condition in Du et al. (2016), and the predictions in the both cues and conflict cues conditions based on the accuracy-based combination model developed in the current study (Equations 2 and 4).

	Observed accuracy			Observed preference for height	Predicted accuracy	Predicted preference for height
	Height	Distance/ angle	Both cues	Conflict	Both cues	Conflict
Exp 1, height vs. distance	0.84	0.82	0.99	0.55	0.96	0.54
Exp 1, height vs. angle	0.74	0.86	0.97	0.39	0.95	0.32
Exp 2, height vs. distance	0.91	0.88	0.99	0.61	0.99	0.58

Figure Captions

Figure 1. An example of the experimental environments (bird's eye view).

Figure 2. Examples of the experimental conditions of Experiments 1 and 2. $\otimes$ denotes the building. Four objects were located at the end of the four streets respectively. X denotes the original location of one target object. At learning, participants were transported to each object at a constant speed by the computer. At testing, participants were released at the center of the intersection and were asked to choose between the two streets denoted by X and Y. X and Y had the same length. When four streets had the same lengths during testing in the B-test-trials, X and Y had the same angular distance from the building, i.e., both closer to the building or both farther away from the building.

Figure 3. Proportion correct in locating target objects as the function of testing cue type and learning cue group in Experiment 1. Error bars represent standard errors of the mean.

Figure 4. Observed and estimated proportion correct in locating target objects when both buildings and street configurations indicated the same orientation (A_{SB}) in the competition group in Experiment 1. Error bars represent standard errors of the mean.

Figure 5. The observed and estimated percentage of choosing the response location indicated by the street configuration when the building and the street configuration were in conflict ($P_{S|Conflict}$) in the competition group in Experiment 1. Error bars represent standard errors of the mean.

Figure 6. Proportion correct in locating target objects as the function of testing cue type and learning cue group in Experiment 2. Error bars represent standard errors of the mean.

Figure 7. Observed and estimated proportion correct in locating target objects when both buildings and street configurations were presented (A_{SB}) in the competition group in Experiment 2. Error bars represent standard errors of the mean.

Figure 8. The observed and estimated percentage of choosing the response location indicated by the street configuration when the building and the street configuration were in conflict ($P_{S|Conflict}$) in the competition group in Experiment 2. Error bars represent standard errors of the mean.
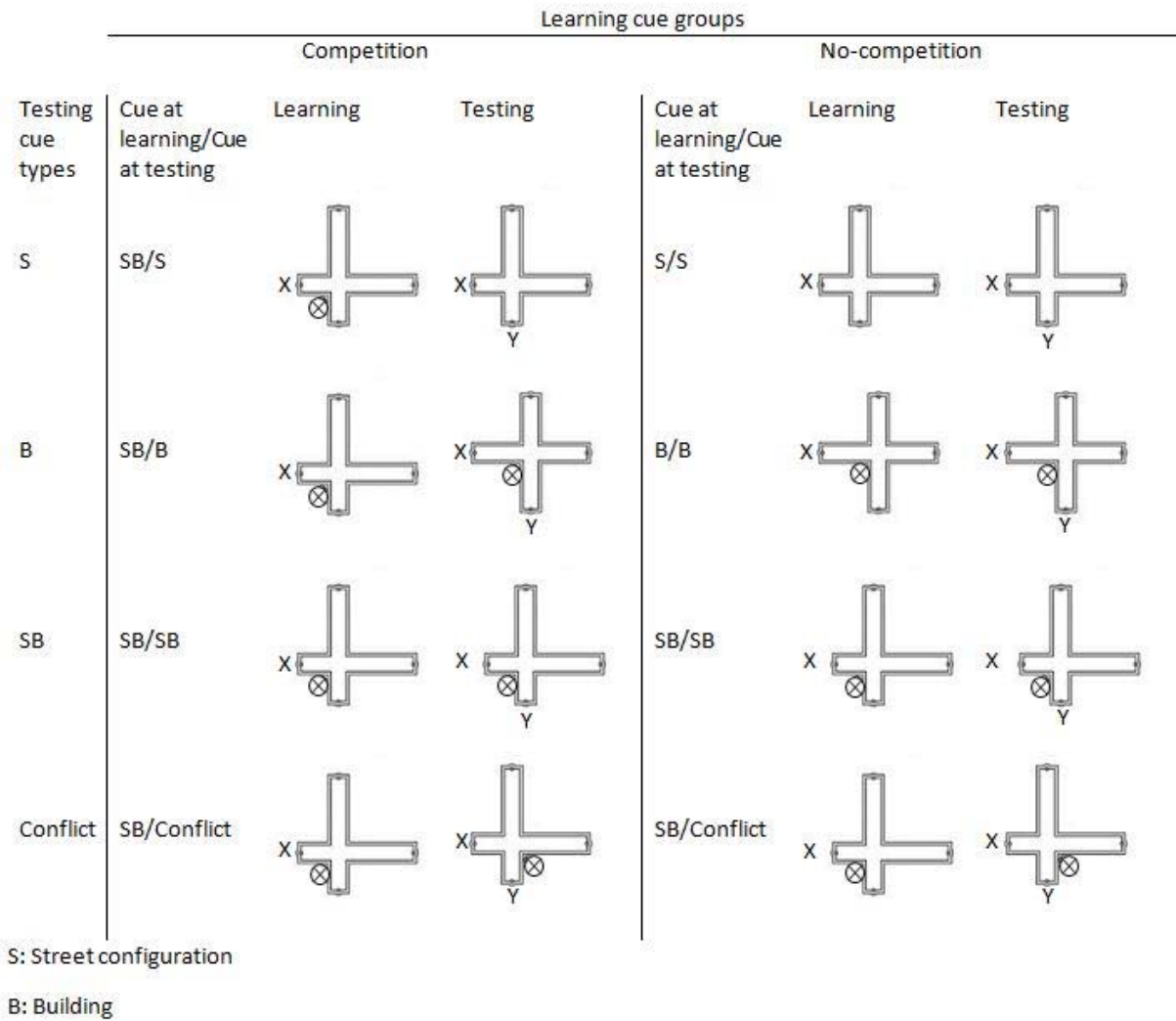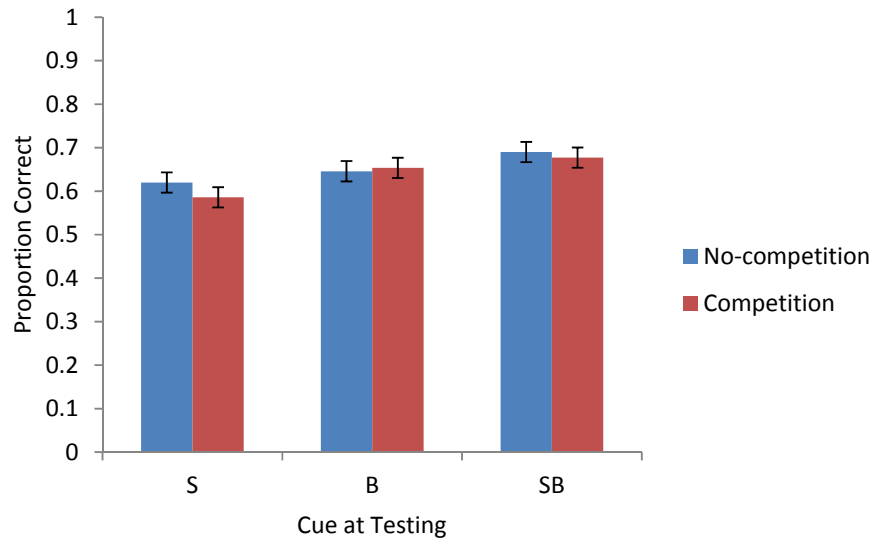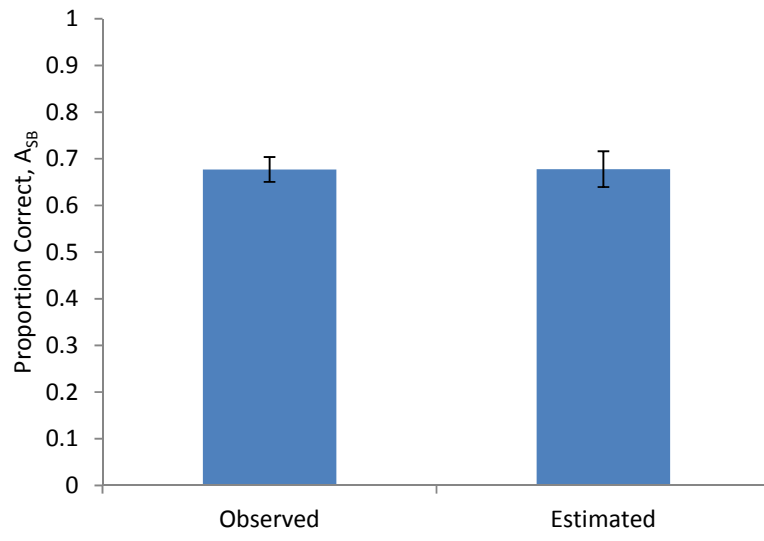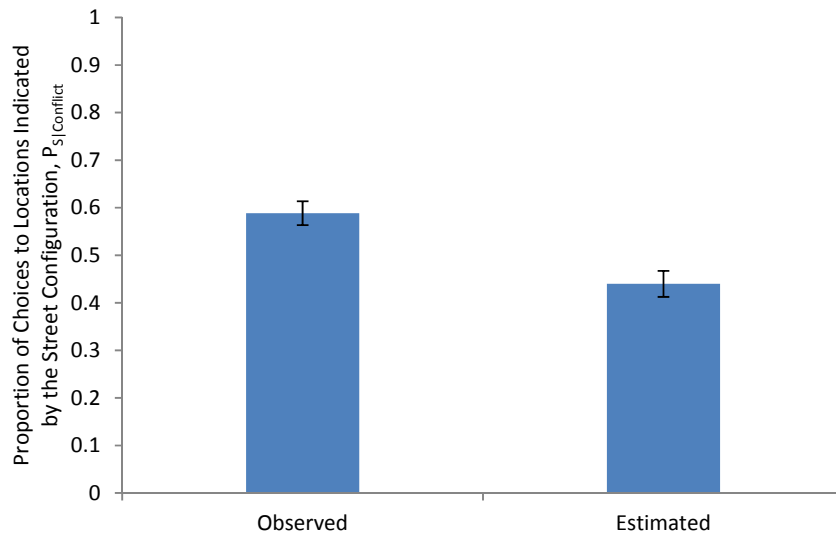
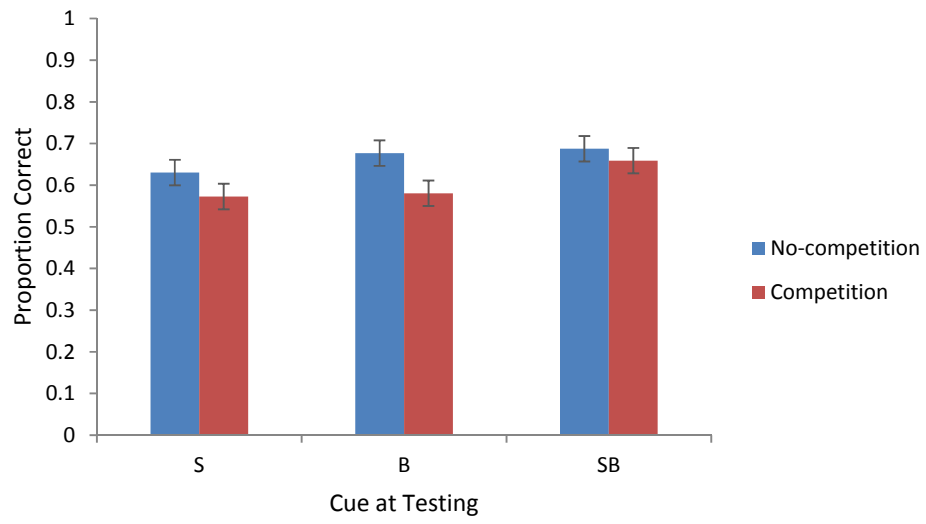Figure 1

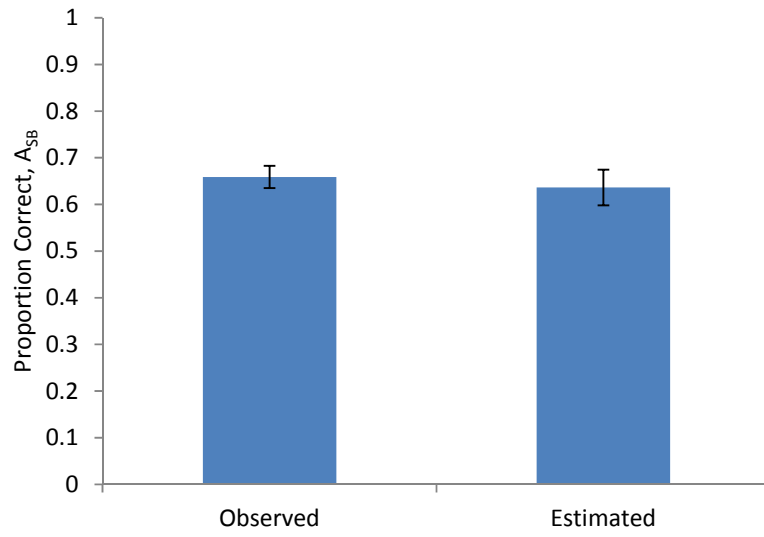Figure 2

S: Street configuration

B: Building
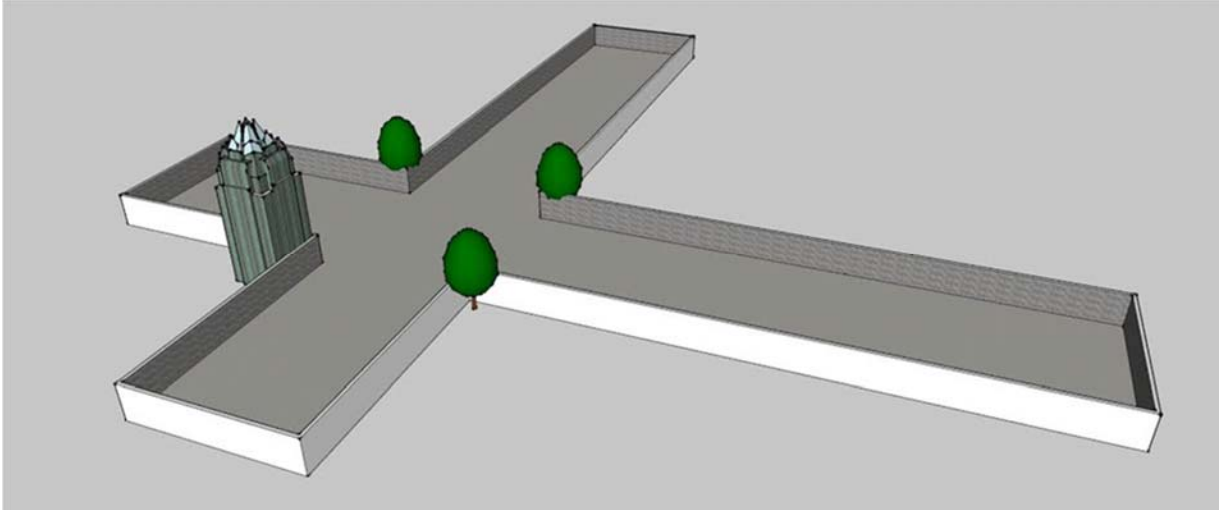
Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8