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Use of Geometric Properties of Landmark Arrays for Reorientation Relative to Remote Cities and Local Objects

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Five experiments investigated how human adults use landmark arrays in the immediate environment to reorient relative to the local environment and relative to remote cities. Participants learned targets' directions with the presence of a proximal 4 poles forming a rectangular shape and an array of more distal poles forming a rectangular shape. Then participants were disoriented and pointed to targets with the presence of the proximal poles or the distal poles. Participants' orientation was estimated by the mean of their pointing error across targets. The targets could be 7 objects in the immediate local environment in which the poles were located or 7 cities around Edmonton (Alberta, Canada) where the experiments occurred. The directions of the 7 cities could be learned from reading a map first and then from pointing to the cities when the poles were presented. The directions of the 7 cities could also be learned from viewing labels of cities moving back and forth in the specific direction in the immediate local environment in which the poles were located. The shape of the array of the distal poles varied in salience by changing the number of poles on each edge of the rectangle (2 vs. 34). The results showed that participants regained their orientation relative to local objects using the distal poles with 2 poles on each edge; participants could not reorient relative to cities using the distal pole array with 2 poles on each edge but could reorient relative to cities using the distal pole array with 34 poles on each edge. These results indicate that use of cues in reorientation depends not only on the cue salience but also on which environment people need to reorient to.

Keywords: navigation, reorientation, landmark array, geometry cue, spatial memory

In everyday life, people need to reorient themselves in the environment after they temporarily lose interaction with the environment, such as when waking from a nap, or after they change environments, such as when exiting from a subway station. Reorientation can be relative to the immediate local environment or to broader environments that are beyond the immediate one. Reorientation relative to the immediate environment enables people to locate goals (objects) in the immediate environment (e.g., locate the bathroom in a house), whereas reorientation relative to the broader environments enables people to know their headings relative to the important landmarks that are beyond the immediate environment (e.g., home, destination city). Although reorientation to the immediate local environment may be necessary for reorientation to the broader environment, reorientation to the immediate local environment does not sufficiently lead to reorientation to broader environment. For example, suppose you are visiting a city for the first time. After you stay in your hotel room for a couple of hours, you should be able to locate objects in your room using the rich visual cues in the room. You, however, probably still do not know your heading relative to broader environments (e.g., the city airport) as the visual information in the room does not readily provide your heading information with respect to broader environments. What cues (e.g., feature vs. geometry shape) people use for reorientation relative to immediate local environment have been extensively investigated. However, there is no study investigating what cues people use for reorientation relative to remote environments and contrasting reorientation to remote and local environments. The current study addressed these issues.

Reorientation requires perceptual information, typically visual information, which can provide directional information independent of the observer's location and orientation. Mathematically, one single distal landmark (e.g., the sun) can provide a directional cue because its direction is unlikely to change while the observer moves within a relatively small environment (Jeffery, 2007; O'Keefe & Nadel, 1978). A group of identical landmarks in the immediate local environment can also specify a unique direction when their configuration cannot be repeated by rotation within 360°. For example, three identical landmarks forming a nonequilateral triangle in the immediate environment can specify a unique direction. The boundary (e.g., the walls) of the immediate environment can also specify a unique direction when the shape of the boundary cannot be repeated by rotation within 360° (Kelly, McNamara, Bodenheimer, Carr, & Rieser, 2008). For example, three walls of a nonequilateral triangle shaped room can specify a unique direction.

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There has been a huge body of studies examining how human and nonhuman animals reorient relative to the immediate local environment using visual cues since the Cheng's (1986) seminal study (see Cheng & Newcombe, 2005, for a review). In one of Cheng's experiments, a rat was trained to find rewards in one corner of a rectangular room. The target corner was distinguished from the diagonal opposite corner based on distinctive objects or features. The results showed that rats after disorientation primarily searched in the target corner and the diagonal opposite (or rotational) corner that was geometrically equivalent with the target corner. This result indicated that rats used the shape of the room for reorientation but did not readily use the distinctive objects or features to avoid the rotational corner (but see Pearce, Graham, Good, Jones, & McGregor, 2006). A similar pattern of results was also observed when human toddlers searched for toys in a rectangular room with one distinctive wall (Hermer & Spelke, 1996). However, human adults primarily searched the correct corner and avoided the rotational corner, indicating they readily use both single object/feature in the local environment and the shape of the room to reorient themselves. Human toddlers can also use single object/feature in the local environment to avoid the rotational corner when the single object/feature is more distal in a larger room (Learmonth, Nadel, & Newcombe, 2002), which is consistent with the idea that the direction of a distal object can indicate a reliable direction (e.g., O'Keefe & Nadel, 1978).

Studies have also contrasted a boundary of the local environment (e.g., walls of a room) and a landmark array within the local environment in reorientation relative to the local immediate environment. Humans can efficiently use the geometric shape of a boundary (e.g., walls of a room) to locate goals within an environment after disorientation (e.g., Hermer & Spelke, 1996; Lee & Spelke, 2010). However, use of the configuration of identical landmarks to locate goals within an environment after disorientation is not as robust (Gouteux & Spelke, 2001; Lee & Spelke, 2010; Reichert & Kelly, 2011).

Gouteux and Spelke (2001) directly compared the roles of a boundary in the local environment and a local landmark array in reorientation. In their experiments, children learned to find a target in one of four bins that formed a rectangular shape in a larger cylindrical room. After disorientation, children searched the bins randomly for the target. These results suggest that children cannot use the shape of a landmark (i.e., bin) array in reorientation. However, children searched the correct bin and the geometrically correct bin (the one diagonally opposite to target) when the bins were connected by extended surfaces (i.e., short walls; Gouteux & Spelke, 2001, Experiment 7). Follow-up studies showed that when the landmark array was placed proximal to the cylindrical enclosure, children also used the shape of the landmark array to find the target (Lee & Spelke, 2010; Lew, Gibbons, Murphy, & Bremmer, 2010). Interestingly, Gouteux and Spelke reported that human adults could use the configuration of the bins to locate the targets without the facilitation of extended surfaces (i.e., short walls).

Recently, Reichert and Kelly (2011) reported that even adult humans failed to locate goals using the global rectangular geometry of a landmark array. In their study, two objects with 50° angles and two objects with 75° angles formed a rectangular shape in a larger rectangular room. Among these objects, the objects at the two geometrically equivalent locations (diagonally opposite to each other) had the same angle information (e.g., 50°). The results showed that adult humans used the angle of individual objects but not the global shape of the object array to locate the target after disorientation. Although it is not clear whether the results occurred because the shape of the landmark array was overshadowed by the room or the appearance of the individual objects, the results suggest that adults' reorientation by landmark arrays may not be as robust as previously thought (e.g., Gouteux & Spelke, 2001).

As a boundary and an array of landmarks are both in the immediate local environment, the superiority of boundaries to drive the reorientation in goal localization might indicate a special role for boundaries in spatial reorientation (e.g., Lee & Spelke, 2010; but see Lew, 2011). Lee and Spelke (2011) argued that a boundary can be used in reorientation because of a dedicated geometric module using the geometry of the boundary as input (e.g., Cheng, 1986). In contrast, Lew (2011) argued that a landmark array and a boundary might be comparable if the landmark array is distantly placed and stable in the environment. Compared to an array of landmarks, a boundary in an environment tends to be relatively stable and distant in the environment, which causes the superiority of a boundary in reorientation. Lew's argument echoed the adaptive combination theory for reorientation (e.g., Newcombe & Ratliff, 2007). According to this theory, the geometric module using the shape of a boundary as input is not necessary. All perceptible cues that mathematically specify directions in the environment can be used for reorientation, and the relative importance of the cues depends on the experienced reliability and salience of the cues.

As reviewed above, a great deal of effort has been devoted to examining how human and nonhuman animals reorient relative to the local immediate environment using an object array and a boundary (e.g., Gouteux & Spelke, 2001; Lee & Spelke, 2010; Lew et al., 2010; see Lew, 2011, for a review). Different theories that favor or oppose a geometry module have been extensively tested. However, it is underexamined whether landmark arrays and boundaries within the local environment differ in their support of reorientation with respect to broader environments. To our knowledge, there is no study directly examining how humans reorient relative to broader environments using an object array and a boundary.

Reorientation to broader environments is indeed a more common spatial task in real life. In everyday life, because people can visually see the immediate environment, it is less likely that people lose their heading relative to the local immediate environment. It is more likely people lose their heading relative to broader environments. When adults lose heading relative to broader environments, for example, when exiting from a subway station, they often try to use the visual cues in the local immediate environment and their spatial representations in memory to recover the bearings of their current position with respect to important landmarks that are beyond the immediate environment (e.g., home, destination city). Hence, it is important to understand how people reorient relative to remote environment using the visual cues in the local environment.

In the current study, we hypothesized that reorientation relative to broader environments is more challenging than reorientation relative to the immediate local environment as the visual information available in the local immediate environment provides stronger orientation cues for the local environment than for the broader environment. The findings that adults can use both landmark arrays and boundaries within the local environment for reorientation relative to the immediate environment do not guarantee that adults can use both landmark arrays and boundaries within the local environment for reorientation relative to the broader environments. Instead, reorientation relative to the broader environment is a challenging task that may require a salient cue. The shape of a boundary can be directly perceived and is more salient than the shape of an object array because the shape of widely separated objects must be mentally formed. Thus, adults may be able to use boundaries but not object arrays in the local environment to reorient to the broader environment. This hypothesis is consistent with the findings that adults used a more salient cue (geometry of a room) but not a less salient cue (feature) in a more challenging task (e.g., Hermer-Vazquez, Spelke, & Katsnelson, 1999; Ratliff & Newcombe, 2008). Adults did not use a distinctive feature to avoid the rotational corner when they were simultaneously conducting a secondary task although they could use a distinctive feature to avoid the rotational corner without the interference of a secondary task (e.g., Hermer & Spelke, 1996). By contrast, adults could use the geometry of a room for reorientation even when they were distracted by a secondary task.

The purpose of the current study was to test the above hypothesis and understand the different roles of a boundary and an array of landmarks in human adults' reorientation relative to broader environments in contrast to a local environment. In Experiment 1, human adults needed to reorient to local environments using separate landmarks (i.e., poles) to replicate the previous finding (Gouteux & Spelke, 2001). Participants learned objects on the floor of the local environment in which four separate poles were presented proximately and four poles were presented distally (see Figure 1). In Experiments 2–5, human adults needed to reorient to multiple remote cities using either an array of four separate landmarks (illustrated in Figure 2A) or a fence-like landmark array (see Figure 2B) in a virtual environment. In Experiments 2–3, the directions of remote cities were learned through map reading (see Figure 3A), whereas in Experiments 4–5, the directions of remote cities were indicated by labels of the hypothetic cities moving back and forth in the corresponding directions (see Figure 3B). This task is relevant to reorientation relative to broader environments. As discussed above, connecting the local visual cue to the heading relative to the broader environment is challenging. Furthermore, learning directions of the cities would direct their attention away from the immediate environment and reduce the attention resources available to process the cues in the immediate environment. Consequently, the cues within the environment that require minimal attention might be processed better and thus be more likely used by participants to recover their heading after disorientation. Hence, we predicted that human adults might use a fence-like landmark array but not an array of four separate landmarks to reorient relative to remote cities.

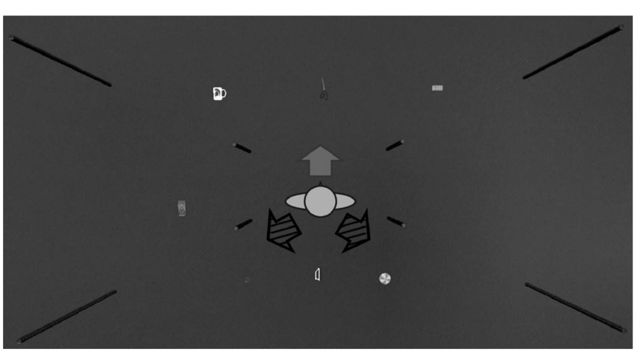

Figure 1. Schematic diagram of the experiment setup (overhead view) for all experiments. The participant faces 0° (facing direction is indicated by the open arrow) when learning the direction of each object (e.g., scissors in Experiment 1) or each city. Both orienting cues are present during learning (i.e., distal indicated by the four-pole brick-textured landmark array and the proximal landmark array indicated by the four shorter poles, seen by the participant as magenta, in Experiment 1). The floor extends infinitely in all experiments, so that it does not provide any orientation cue. The line-patterned arrows indicate the 120° and 240° facing orientations of the participant during testing.

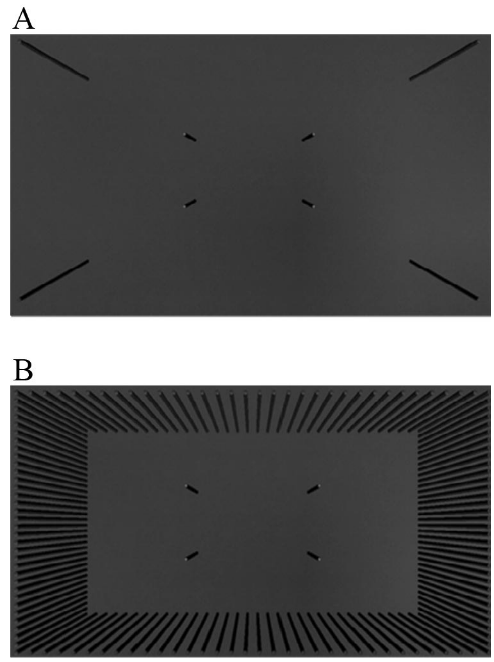

Figure 2. Overhead view of the orienting cues used in all the experiments. Panel A is for Experiments 1, 2, and 4. Panel B is for Experiments 3 and 5. Note that the floor extends infinitely in all experiments, so that it does not provide any orientation cue.

Experiment 1

Participants learned the locations of seven objects in the local environment from a single viewpoint and in the presence of two orienting cues: a distal array and a proximate array of identical landmarks (i.e., poles; see Figures 1 and 2A). Once learning was completed, participants pointed to the locations of the objects under three experimental conditions: In the baseline condition, participants pointed to the objects while facing the learning orientation and with the two orienting cues present; in the first disorientation condition, participants were disoriented and then turned to a new facing direction (120° or 240°; see line-patterned arrows in Figure 1) before pointing in the presence of only one of the two orienting cues (e.g., distal or proximal poles); and in the second

A

B

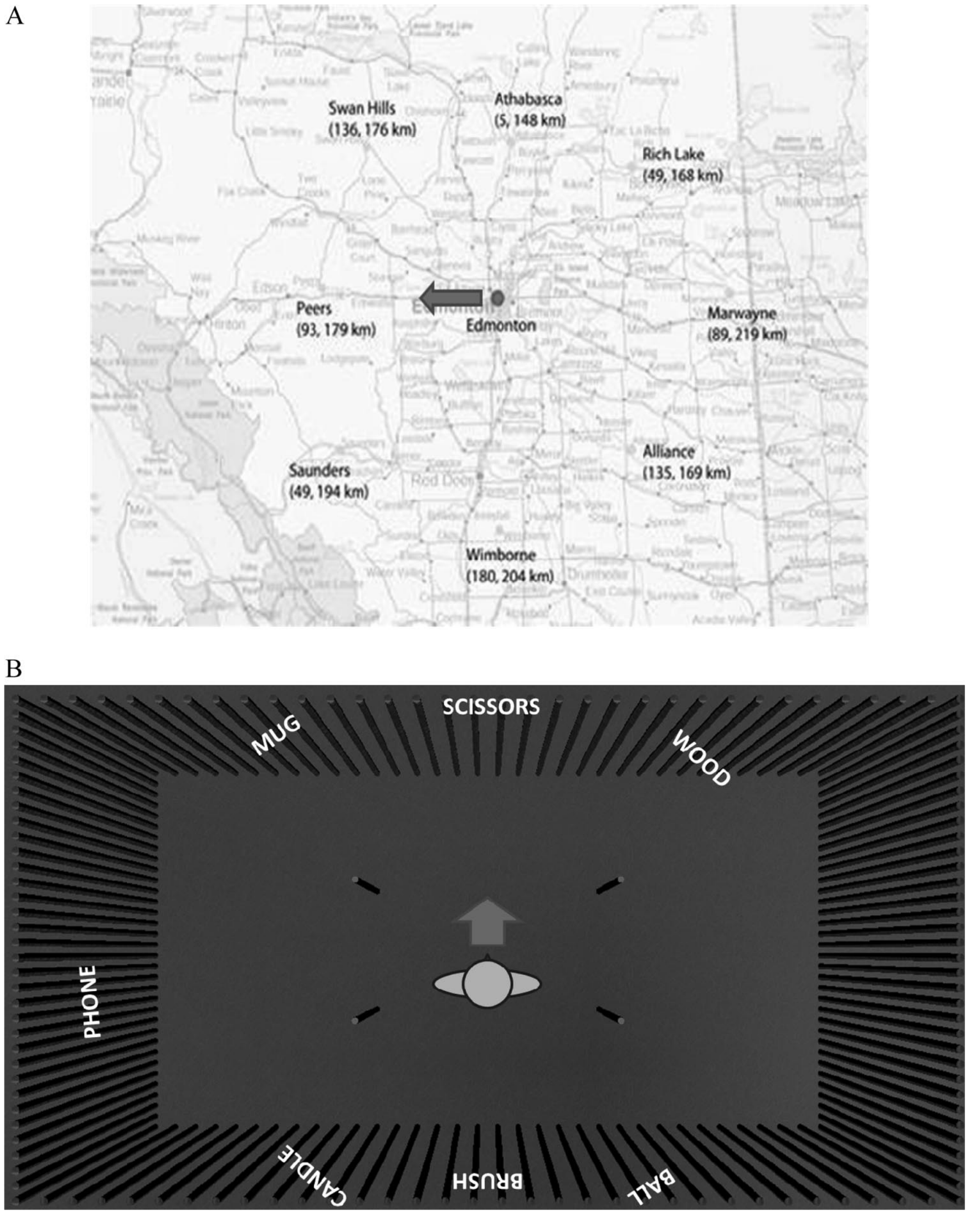

Figure 3. Panel A shows a map highlighting the location of the cities used in Experiments 2 and 3 (facing direction during learning the directions of the cities in the virtual environment is indicated by the arrow). Panel B shows the schematic diagram (overhead view) of the setup for Experiment 5. While keeping the direction constant, each city's name moved continually to and from the standing position of the participants between 1.4 m and 6.4 m from the participant at speed of 2.5 m/s. The texts of the cities were always visible, even when they translated behind the walls.

disorientation condition, participants were again disoriented and then turned to a new facing direction (120° or 240°; see line-patterned arrows in Figure 1) before pointing to the cities in the presence of the remaining orienting cue (e.g., proximal or distal poles). The purpose of this experiment was to replicate the finding that adults could use an array of separated landmarks for reorientation relative to local environments. We also used both a distal landmark array and a proximate landmark array to determine whether people might only be able to use the distal landmark array. The baseline condition was used to determine whether participants' memory about the target location was accurate. Each participant had all these three conditions.

Method

Participants. Thirty-two university students (16 men, 16 women) from introductory psychology classes at the University of Alberta (Edmonton, Alberta, Canada) participated in this experiment. They received partial course credit for their participation.

Apparatus and design. The experiment took place in a 4-m × 4-m physical cylindrical room. The stimuli were displayed with an nVisor SX60 head-mounted display (HMD; NVIS, Inc., Virginia). Graphics were rendered using Vizard software (WorldViz, Santa Barbara, California). The projected field of view is 49° horizontally and 40° vertically. Head orientation was tracked with an InterSense IS-900 motion tracking system (InterSense, Inc., Massachusetts). The distal array seen by the participants consisted of four identical brick-textured poles (each 3 m in height) that formed a rectangular array measuring 6 m × 3 m (called distal array; see Figures 1 and 2A). The second orienting cue seen by the participants consisted of four magenta poles (each measuring 1.7 m in height and 5 cm in diameter) that formed a 2 m × 1 m rectangular configuration (called proximal array). The floor had no texture and extended infinitely such that it would not provide any orientation information. Both landmark arrays had the same center and their principal axes were aligned in the same direction.

Participants' learning orientation, as illustrated by the open arrow in Figure 1, was parallel to the short axis of the proximal and distal landmark arrays. Participants' learning position, as illustrated in Figure 1, was 30 cm from the center of the arrays. White noise was played through the earphone of the HMD in order to negate any potential auditory orienting cues. During the learning phase of the experiment, the objects (i.e., scissors, wood, ball, brush, candle, phone, and mug) were visible on the floor. Each object appeared at a specific direction within the virtual world relative to the learning position and the learning orientation of the participants: scissors at 5°, wood at 49°, ball at 135°, brush at 180°, candle at 229°, phone at 273°, and mug at 316°. The participants were told explicitly that they would learn the location of the seven objects around them ("Your task is to remember the location of the objects around you"). For each test trial, instructions as to which object was the target were presented by a computer via wireless earphone. A joystick was used as the pointing apparatus.

The independent variable was the visual orienting cue available (i.e., distal landmark array and/or proximal landmark array; see Figure 1). In the baseline condition, both distal and proximal landmark arrays were available while the participants faced 0° (i.e., the same facing direction as in the learning phase; see Figure 1). In each disorientation condition, the participants were blindfolded, rotated in place for 1 min, and then told to point to an object (ball or candle) named by the experimenter. Participants kept on rotating until the absolute pointing error was larger than 45° to ensure that they were disoriented. The participants were then turned by the experimenter to face a new heading (120° or 240°; see line-patterned arrows in Figure 1) before removing the blindfold and pointing to the objects in the presence of only one orienting cue (distal or proximal landmark array). In each condition, a total of 28 trials were given, four trials for each of the seven objects. The cue condition (distal or proximal landmark array) and the facing direction (120° or 240°; see line-patterned arrows in Figure 1) in the two disorientation conditions were counterbalanced across participants.

The dependent variable was the subjective heading, which was assumed to be the heading adopted by the participant while pointing to the objects (e.g., Mou, McNamara, Rump, & Xiao, 2006; Wang & Spelke, 2000). The subjective heading can be inferred by the constant angular error when participants point to objects because the discrepancy between the actual heading and the subjective heading produces the constant angular error. For example, if the participant's actual test heading is 120° in one disorientation condition but the participant thinks that his or her heading is 67°, for each trial, there will be a constant angular error of 53°.

In order to calculate the subjective heading, we measured (a) the *signed pointing error*, defined as the signed angular difference (linearized between −180° and 180°) between the judged direction of the target object and the actual direction of the target object. The actual direction of a target object was defined with respect to the participant's egocentric heading, that is, the learning heading (baseline) or to the 120° and 240° headings in the disorientation conditions. The judged direction was also defined with respect to the participant's egocentric heading, (b) the *heading error,* defined as the mean of the signed pointing errors. Heading error measures the constant error in pointing judgments (Wang & Spelke, 2000). Because the discrepancy between the actual heading and the subjective heading produces the constant angular error (i.e., heading error), the subjective heading was estimated as the difference between the participant's actual heading and the heading error. The *configuration error,* defined as the standard deviation of the mean signed pointing errors of each target object, was also reported as this measure may be interesting to some readers (e.g., Wang & Spelke, 2000). Furthermore, a small configuration error might indicate that the subjective heading estimated by the heading error was exactly the heading that participants adopt at pointing rather than the mean of several random pointing errors. In addition, a small configuration error in the baseline condition also indicated accurate memories of the target directions after people learned the targets and maintained their learning heading.

Procedure. After providing informed consent, the participant received instructions and was trained on how to use a joystick to make relative direction judgments. The participant was then blindfolded and led to the experimental room. He or she was led to the learning position and orientation and then put on the HMD. In the virtual environment, the participant saw the landmark arrays and the objects on the floor. The participants were explicitly instructed to learn the location of the seven objects around them.

The participant was instructed to look around, point to each pole in the distal landmark array, point to each pole in the proximal landmark array, and point toward and name the objects. During the learning phase, the participant was given six 30-s sessions to learn the direction of all the objects. Observation of the participants indicated that they were all able to point to the objects accurately by the end of these six sessions, and this was confirmed by the pointing performance in the baseline condition at test. The participant faced 0° (i.e., learning direction) but was permitted to turn his/her head to learn the directions of the objects. After each learning session, all the visual information disappeared, and the participant was asked by the experimenter to point to the objects. Although this procedure may encourage participants to ignore the visual cues, this would apply equally to both the landmark arrays. Feedback was given by the experimenter. Once the learning phase was completed, the baseline condition began. The participant stayed facing the learning direction. Both the landmark arrays were presented, but no objects were visible. Once again, the participant was asked to look around and point to each pole of the distal and proximal landmark arrays. The target object that the participant had to point to was given by an automated voice through the HMD (e.g., "Please point to candle"). Participants held the joystick against their waist facing forward during pointing. Pointing direction depend on the viewing direction. The participant received no feedback during this condition. After the baseline condition, participants were tested in the two disorientation conditions. Before the test trials in each disorientation condition, the participants took off the HMD with their eyes closed and were then blindfolded so they did not visually engage in the real environment and presumably still engaged in the virtual environment. In order to remove the idiothetic cue, participants were asked to rotate on the spot for 60 s.

To ensure he or she was disoriented, the participant was asked to point in the direction of an object while blindfolded. If he or she pointed within 45° of the target city, the participant was asked to rotate for another 30 s. Otherwise, the participant donned the HMD again. In each disorientation condition, only one of the two orienting cues (distal or proximal landmark array) was present. Based on a prerandomized order, the participant faced either 120° or 240°. Once again, the participant was asked to look around and point to each of the landmarks. The target object that the participant had to point to was again given by an automated voice through the HMD. The participant also received no feedback during the disorientation conditions.

Data analysis. To analyze the data, we classified the subjective headings into six categories (0°, 60°, 120°, 180°, 240°, and 300°), and a subjective heading within ±30° around a category (e.g., 30° to 90° for the category of 60°) was counted as that category (i.e., 60°). Subjective headings that were close to 0° (± 30°) were classified as *learning* given that these participants acted as if they were facing the same direction as during learning. For the condition in which participants faced 120°, the subjective headings that were either at 120° (± 30°) or 300° (± 30°) were summed into a category called *fit* because the data fit the prediction that the participants would either accurately identify their current heading or make rotational errors (i.e., 180°) when they effectively used the rectangular shape of the landmark array. Similarly, for the condition in which participants faced 240°, the subjective headings that were either 240° (± 30°) or 60° (± 30°) were summed into the fit category. Any other heading was classified as *other.* Whether the participants were orienting randomly was tested using a chi-square test (Batschelet, 1981). If the participants are able to reorient using the visual cue provided, then the fit category will be significantly above chance (two out of six, or 33.3%). If the participants just assume the learning heading as their direction, then the learning category will be significantly above chance (one out of six, or 16.7%). However, if the participants are not able to reorient and adopt a random subjective heading, then none of the categories (fit, learning, and other) will be significant. We also directly compared the frequencies in the fit category of the two visual cues conditions.

Results

The distribution of subjective headings in each condition is plotted in Figures 4A–4C as a function of actual heading. As shown in Figure 4A, the subjective headings of participants in the baseline condition all fell within the learning category. Therefore, no statistical analyses were necessary. In the disorientation condition in which the participants had only the proximal landmark array as the orientation cue (see Figures 4B and 4D), the frequency of subjective headings that fell within the fit category was eight (25%) and not significantly different from the chance level (33.3%), $\chi^2_{\text{Fit}}(1) = 1$, $p = .32$. The frequency of subjective headings in the learning category was, however, 12 (37.5%) and significantly greater than chance (16.7%), $\chi^2_{\text{Learning}}(1) = 10.00$, $p = .002$. In contrast, in the distal landmark array condition (see Figures 4C and 4D), the frequency of subjective headings in the fit category was 17 (53.1%) and above chance (33.3%), $\chi^2_{\text{Fit}}(1) = 5.64$, $p = .02$, and in the learning category was 9 (28.1%) and not different from chance (16.7%), $\chi^2_{\text{Learning}}(1) = 3.03$, $p = .08$. Thus, the data suggest that most participants relied on geometric information provided by the distal landmark array to reorient. However, when only the proximal landmark array was present, statistically significant numbers of participants assumed the learning direction as their heading and did not use the geometric information of the array. We also directly compared the frequencies in the fit category of the two visual cues conditions. The frequency of subjective headings in the fit category for the distal array condition was larger than for the proximal array condition (53.1% vs. 25%), $\chi^2(1) = 5.32$, $p = .021$.

The configuration error in this and all following experiments was fairly small in all conditions (see Table 1) which ensured that the subjective heading estimated above was the heading that participants adopted in pointing to the objects. Furthermore the configuration error in this experiment was comparable to that in all following experiments, $F(4, 123) = 0.87$, which indicated that participants learned the targets' directions accurately in all experiments.

Discussion

The main finding from Experiment 1 is that human adults (53% of participants) are able to reorient to multiple objects within the local environment by using the geometric information from a distal landmark array. This finding is consistent with the results from studies using a single hidden object in the immediate environment (reviewed in Cheng & Newcombe, 2005). Furthermore, among the other 15 participants who did not use the room geometry for reorientation, nine of them used the learning view as their subjective heading in the room condition, which indicated that people tended to use their learning heading as the subjective heading if they could not reorient themselves (Mou et al., 2006).

Previous research using the goal localization paradigm has shown that human adults, unlike children, are able to extract the geometric properties of an array of objects to reorient (Gouteux & Spelke, 2001; but see Reichert & Kelly, 2011). The results of Experiment 1 were congruent with those in Gouteux and Spelke (2001) for the distal landmark array. In the proximal landmark array condition, the participants did not use the landmark array to reorient (only eight out of 32). Taken together, the results of Experiment 1 suggest that human adults can use the geometric information provided by a distal landmark array but not the geometric information provided by a more proximal landmark array to reorient to multiple objects. Most human adults who could not reorient used their original learning heading as their subjective heading.

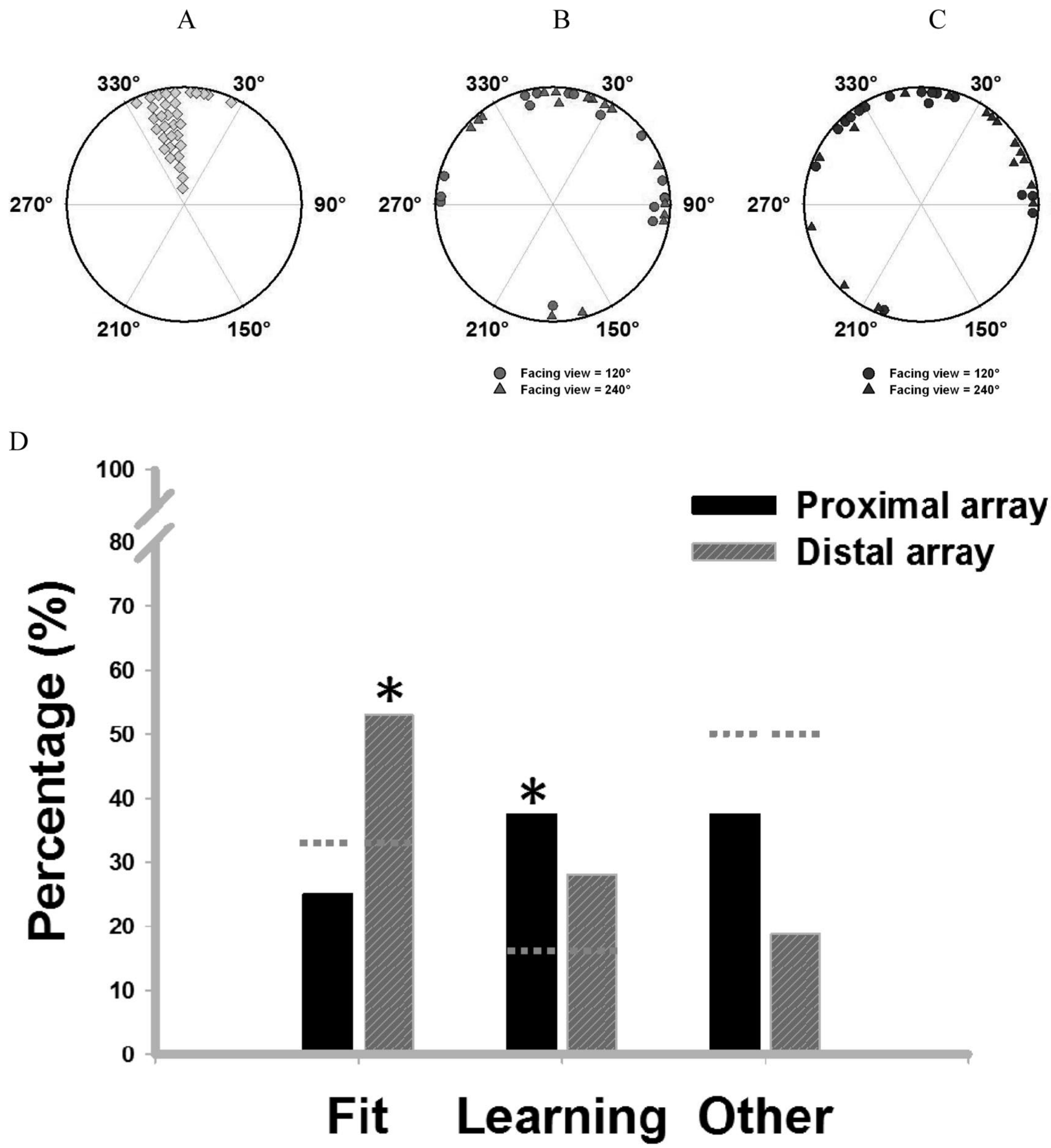

Figure 4. Distribution of the subjective headings in Experiment 1. Panel A shows the distribution for the baseline condition. Panel B shows the distribution for the proximal landmark array condition. Panel C shows the distribution of subjective headings for the distal landmark array condition. Panel D shows the frequency of subjective headings within the fit category (expected heading if orienting cue was used), learning category (expected if participant assumed the same heading as the learning heading), and other (heading not within the fit or learning category) in the two disorientation conditions (proximal landmark array vs. distal landmark array) in Experiment 1. The dotted line in each condition represents the chance level. * $p < .05$.

However, it is often the case that humans have to reorient to multiple distant objects that are not visible in the immediate environment (e.g., reorienting to multiple street locations upon exiting the subway). It is currently unknown whether the cognitive process involved in reorienting to distant invisible objects is different from reorienting to objects within the local environment. Therefore, we conducted Experiment 2 in which participants learned the location of seven cities from a map (see Figure 3A) and were then tested in a virtual environment containing arrays of landmark similar to Experiment 1. This experiment will provide the answer to the question of whether humans can use local geometric cues to reorient to multiple distant invisible cities.

Experiment 2

Participants learned the locations of seven cities relative to Edmonton (Alberta, Canada) from a map (see Figure 3A). Thereafter, the participants were introduced to a virtual environment that

Table 1
Mean (and Standard Deviation) Configuration (in Degrees) for Each Experimental Condition in All Five Experiments

	Condition			
Experiment	B	D	P	Comparison
1	13.52 (6.17)	20.61 (7.92)	23.80 (19.74)	B < D; B < P; D = P
2	15.65 (8.86)	21.97 (17.53)	16.41 (8.10)	B = D; B = P; D = P
3	18.67 (16.22)	34.06 (25.12)	32.44 (22.66)	B < D; B < P; D = P
4	15.28 (11.30)	16.73 (15.49)	15.84 (10.45)	B = D; B = P; D = P
5	15.92 (7.116)	14.49 (5.46)	17.44 (10.90)	B = D; B = P; D = P

Note. $n = 24$ in all experiments except Experiment 1 ($n = 32$). In the Comparison column, < refers to significantly smaller at the .05 level, and = refers to no significant difference at the .05 level. B = baseline condition; D = distal cue condition; P = proximal cue condition.

provided two orienting cues: a distal array and a proximate array of identical landmarks (i.e., poles; see Figure 2A) as in Experiment 1. Participants were then trained to point accurately to the direction of each of the seven learned cities from a single viewpoint. Once learning was completed, participants pointed to the direction of the cities in three experimental conditions: a baseline condition and two disorientation conditions. However, unlike Experiment 1, instead of objects on the floor, participants learned the location of real cities (i.e., Rich Lake, Marwayne, Alliance, Wimborne, Saunders, Peers, Swan Hills) that surround Edmonton from a map.

Method

Participants. Twenty-four university students (12 men, 12 women) from introductory psychology classes at the University of Alberta participated in this experiment. They received partial course credit for their participation.

Apparatus, design, and procedure. The apparatus, design, and procedure were similar to those used in Experiment 1. Both orienting cues were identical to the ones used in the Experiment 1 (i.e., distal and proximal landmark arrays). The proximal array was used in this and all following experiments to make all the experiments comparable. Participants were given 2 min to learn the locations of seven cities around Edmonton from the map before they were led to the virtual reality room while blindfolded. In the virtual reality room, with the presence of the two orientation cues, participants were instructed to imagine themselves in a room in Edmonton, face the direction of Peers, and then point to all the cities they learned on the map. Six practice sessions were included. In each session, participants looked around the environment with the poles presented for 30 s. Then the poles disappeared. Participants were required to point to the seven cities in a random order, one pointing trial for each city per session. The participants used their hands to point during the first five sessions, and the experimenter gave participants feedbacks by directing their hands to the correct directions if participants pointed in a wrong direction. At the sixth practice session, participants pointed to the cities using the joystick. Then the testing trials started. The baseline and disorientation test trials were the same as in Experiment 1 except that participants were asked to point in the direction of target cities rather than local objects.

Results and Discussion

The distribution of the subjective heading in each condition is plotted in Figures 5A–5C as a function of actual heading. The subjective heading of the participants in the baseline condition all fell within the learning category (see Figure 5A) except for one. The frequency of subjective headings within the learning category in the proximal array condition was six (25.0%) and not significantly different than chance (16.7%), $\chi^2_{\text{Learning}}(1) = 1.20$, $p = .27$ (see Figures 5B and 5D). The frequency of subjective headings within the fit category in the proximal array condition was 10 (41.7%) and not significantly greater than the chance level (33.3%), $\chi^2_{\text{Fit}}(1) = 0.75$, $p = .39$. The frequency of subjective headings within the learning category in the distal array condition was nine (37.5%) and significantly higher than chance (16.7%), $\chi^2_{\text{Learning}}(1) = 7.50$, $p = .006$ (see Figures 5C and 5D), whereas the frequency of subjective headings within the fit category was eight (33.3%) and not significantly different from the chance level (33.3%), $\chi^2_{\text{Fit}}(1) = 0$, $p = 1.0$. We also directly compared the frequencies in the fit category of the two visual cues conditions. The frequency of subjective headings in the fit category for the distal array condition and for the proximal array condition (33.3% vs. 41.7%) did not differ, $\chi^2(1) = 0.36$, $p = .55$.

The results from Experiment 1 and Experiment 2 suggest that humans are not able to use an array of identical landmarks in the immediate environment to reorient to multiple remote cities and that this process may be different from reorienting to local objects that are in the immediate environment. These results are in conflict with the finding that human adults are able to reorient to locate a single object using a landmark array. We hypothesized that the difference may be due to the cognitive effort required to reorient to multiple remote cities when the orienting cue is not very salient (see Newcombe & Ratliff, 2007). Therefore, we conducted Experiment 3 in which we increased the saliency of the shape of the distant landmark array by increasing the number of poles within the array.

Experiment 3

Participants saw a distal array consisting of 34 brick-textured poles on each side of the rectangle. The poles were spaced equally within a side, but the spacing differed for the long and short sides,

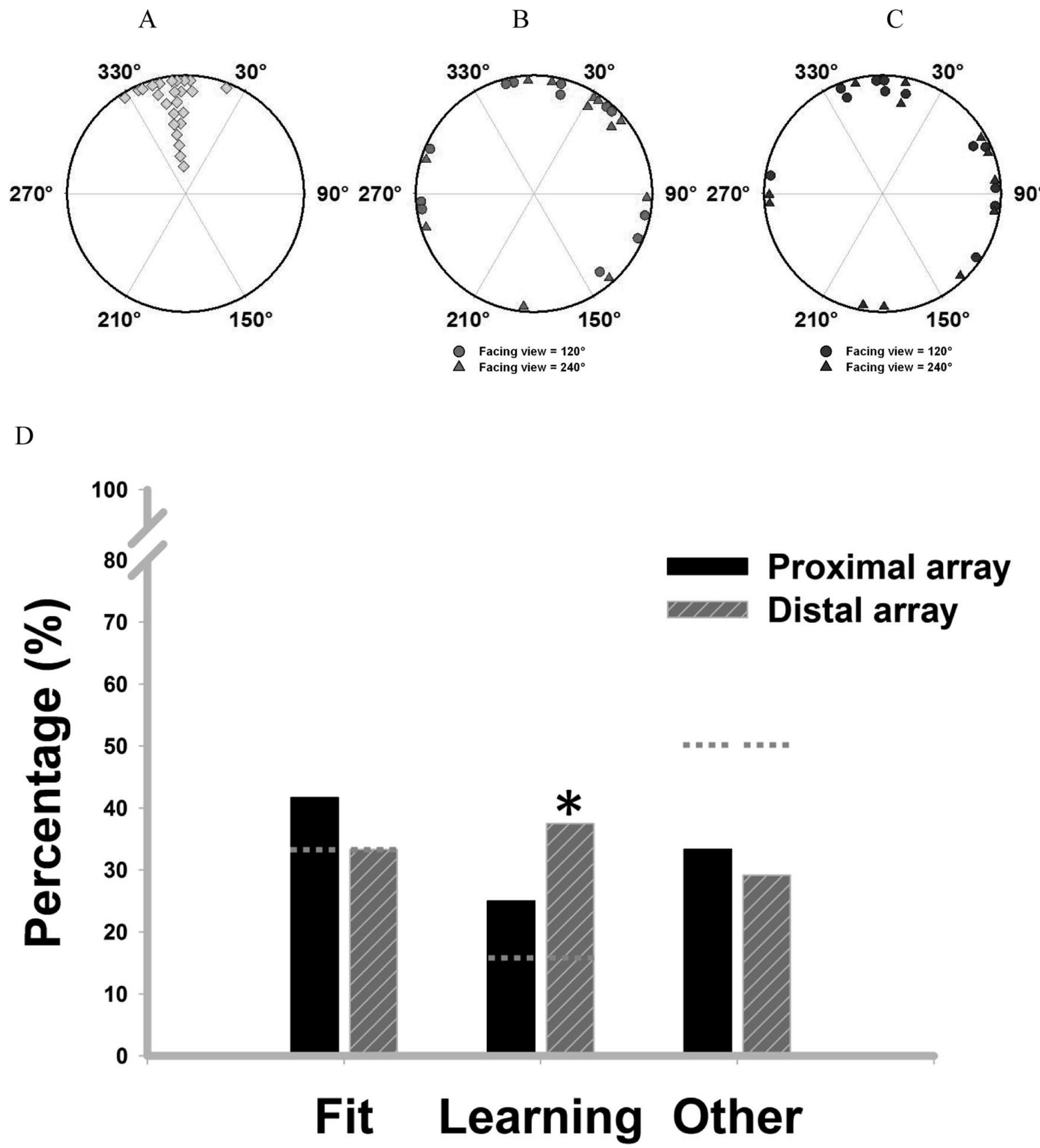

Figure 5. Distribution of the subjective headings in Experiment 2. Panel A shows the distribution for the baseline condition. Panel B shows the distribution for the proximal landmark array condition. Panel C shows the distribution of subjective headings for the distal landmark array condition. Panel D shows the frequency of subjective headings within the fit category (expected heading if orienting cue was used), learning category (expected if participant assumed the same heading as the learning heading), and other (heading not within the fit or learning category) in the two disorientation conditions (proximal array vs. distal array) in Experiment 2. The dotted line in each condition represents the chance level. * $p < .05$.

with a gap of ~13 cm on the long side and ~4 cm on the short side, as shown in Figure 2B.

Method

Participants. Twenty-four university students (12 men, 12 women) from introductory psychology classes at the University of Alberta participated in this experiment. They received partial course credit for their participation.

Apparatus, design, and procedure. The apparatus, design, and procedure were similar to those used in Experiment 2. The orienting cues seen by participants consisted of (a) a proximal array consisting of four magenta poles as used in the previous experiments and (b) a distal fence-like array as shown in Figure 2B.

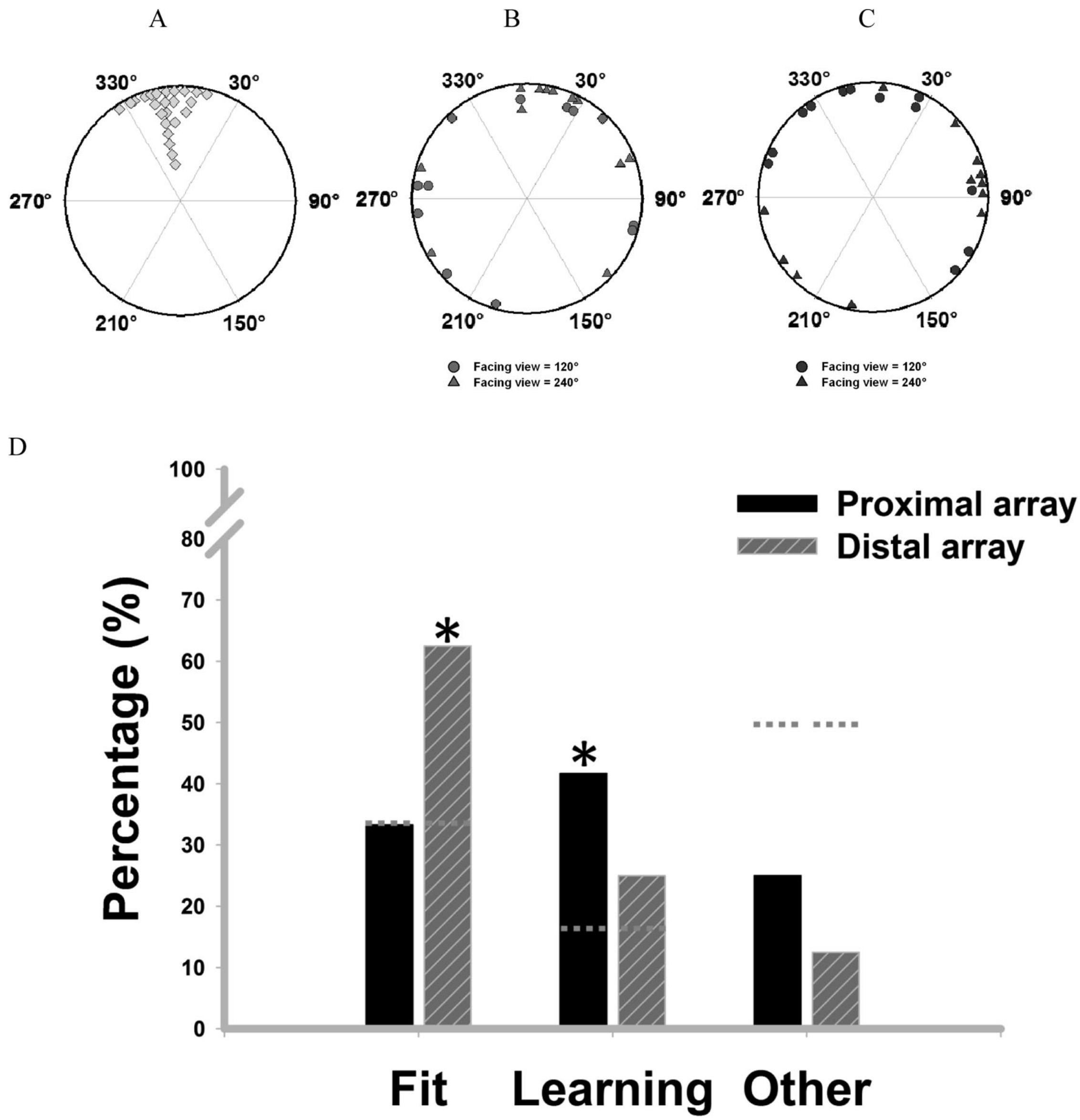

Figure 6. Distribution of the subjective headings in Experiment 3. Panel A shows the distribution for the baseline condition. Panel B shows the distribution for the proximal landmark array condition. Panel C shows the distribution of subjective headings for the distal landmark array condition. Panel D shows the frequency of subjective headings within the fit category (expected heading if orienting cue was used), learning category (expected if participant assumed the same heading as the learning heading), and other (heading not within the fit or learning category) in the two disorientation conditions (proximal array vs. distal array) in Experiment 3. The dotted line in each condition represents the chance level. $^{*}\ p < .05$.

Results and Discussion

The distribution of the subjective heading in each condition is plotted in Figures 6A–6C as a function of actual heading. The subjective heading of the participants in the baseline condition all fell within the learning category (see Figure 6A) except for one. As illustrated in Figures 6B and 6D, the frequency of subjective headings within the learning category in the proximal array condition was 10 (41.7%) and significantly higher than chance (16.7%), $\chi^2_{\text{Learning}}(1) = 10.80$, $p = .001$. However, the frequency of subjective headings within the fit category in the proximal array condition was eight (33%) and not significantly different from the chance level (33%), $\chi^2_{\text{Fit}}(1) = 0$, $p = 1$. The different pattern of results was found in the distal array condition (see Figures 6C and 6D). The frequency of subjective headings within the learning category in the distal array condition was six (25%) and not significantly different from chance (16.7%), $\chi^2_{\text{Learning}}(1) = 1.20$, $p = .27$, whereas the frequency of subjective headings within the fit category was 15 (62.5%) and significantly higher than the chance level (33.3%), $\chi^2_{\text{Fit}}(1) = 9.19$, $p = .002$. We also directly compared the frequencies in the fit category of the two visual cues conditions. The frequency of subjective headings in the fit category for the distal array condition and for the proximal array condition (62.5% vs. 33.3%) differed significantly, $\chi^2(1) = 4.09$, $p = .04$.

A potential issue with the experiments discussed thus far is that there is a possibility that the differences observed between Experiment 1 and Experiment 2 are related to the differences in learning. There are two differences. First, the difference may stem from the fact that in Experiment 1, objects were learned within the virtual environment, whereas in Experiment 2, the cities were learned prior to entering the virtual environment. Second, the difference may occur because object names were used in Experiment 1 (i.e., scissors, wood, ball, brush, candle, phone, and mug), whereas city names were used in Experiment 2 (Rich Lake, Marwayne, Alliance, Wimborne, Saunders, Peers, Swan Hills). To address this issue, we devised two experiments (Experiments 4 and 5) in which the directions of the cities were learned within the virtual environment and with the use of labels instead of a map. To make sure that the names of the targets would not be any confounding factors, we used objects' labels to indicate the directions of cities.

Experiment 4

During the learning phase of the experiment, the hypothetical cities' names (i.e., Scissors, Wood, Ball, Brush, Candle, Phone, and Mug) appeared in white text (size of 5 cm, height of 1.5 m; see Figure 3B) in the virtual environment. We used the same object names as in Experiment 1 to avoid the confounding difference in using object names in Experiment 1 and city names in Experiment 2. The orientation cues were the same as in Experiments 1 and 2, four distal poles and four proximal poles.

Method

Participants. Twenty-four university students (12 men, 12 women) from introductory psychology classes at the University of Alberta participated in this experiment. They received partial course credit for their participation.

Apparatus, design, and procedure. The apparatus, design, and procedure were similar to those used in Experiments 1 and 2. However, participants did not learn maps. Instead, each hypothetical city's name appeared at a specific direction within the virtual world in terms of the learning position and the learning orientation of the participants: Scissors at 0°, Wood at 67°, Ball at 120°, Brush at 180°, Candle at 240°, Phone at 282°, and Mug at 325°. While keeping the direction constant, each city's name moved continually to and from the standing position of the participants between 1.4 m and 6.4 m from the participant at speed of 2.5 m/s. The texts of the cities were always visible, even when they translated behind the walls. Thus, participants could only learn the directions and not specific locations of the cities. Furthermore, participants were told explicitly that they would learn the directions of seven cities around them ("Your task is to remember the direction of the cities around you").

Results and Discussion

The distribution of the subjective heading in each condition is plotted in Figures 7A–7C as a function of actual heading. The subjective heading of the participants in the baseline condition all fell within the learning category (see Figure 7A) except for one participant. The frequency of subjective headings within the learning category in the proximal array condition was 19 (79.2%) and significantly higher than chance (16.7%), $\chi^2_{\text{Learning}}(1) = 67.50$, $p < .001$ (see Figures 7B and 7D). However, the frequency of subjective headings within the fit category in the proximal array condition was three (12.5%) and significantly below the chance level (33.3%), $\chi^2_{\text{Fit}}(1) = 4.69$, $p = .030$. The same pattern of results was found in the distal array condition (see Figures 7C and 7D). The frequency of subjective headings within the learning category in the distal array condition was 18 (75%) and significantly higher than chance (16.7%), $\chi^2_{\text{Learning}}(1) = 58.80$, $p < .001$, whereas the frequency of subjective headings within the fit category was five (20.8%) and not significantly different from the chance level (33.3%), $\chi^2_{\text{Fit}}(1) = 1.69$, $p = .194$. We also directly compared the frequencies in the fit category of the two visual cues conditions. The frequency of subjective headings in the fit category for the distal array condition and for the proximal array condition (20.8% vs. 12.5%) did not differ, $\chi^2(1) = 0.60$, $p = .439$.

Experiment 5

The purpose of Experiment 5 was to replicate Experiment 3 except that participants learned the directions of the remote cities by seeing the hypothetical city name moving back and forth in the virtual environment instead of learning city directions on a map.

Method

Participants. Twenty-four university students (12 men, 12 women) from introductory psychology classes at the University of Alberta participated in this experiment. They received partial course credit for their participation.

Apparatus, design, and procedure. The apparatus, design, and procedure were similar to those used in Experiment 4. The orienting cues used consisted of (a) a proximal array consisting of four poles as used in Experiment 4 and (b) a distal array of brick-textured poles that formed a rectangular configuration 6 m ×y 3 m. However, unlike the four-pole distal array of Experiment 4, this array was the same as that used in Experiment 3 and consisted of 34 poles on each side with a gap of ~13 cm on the long side and ~4 cm on the short side (see Figure 2B). Hence the array was not enclosed but the shape of the configuration was readily perceivable.

Results and Discussion

The distribution of the subjective heading in each condition is plotted in Figures 8A–8C as a function of actual heading. As in the previous experiments, the subjective headings of the participants in the baseline condition all fell within the learning category (see Figure 8A). Similar to previous experiments, in the proximal array condition (see Figures 8B and 8D), the frequency of subject heading within the learning category was 14 (58.3%) and significantly greater than chance (16.7%), $\chi^2_{\text{Learning}}(1) = 30.00$, $p <$

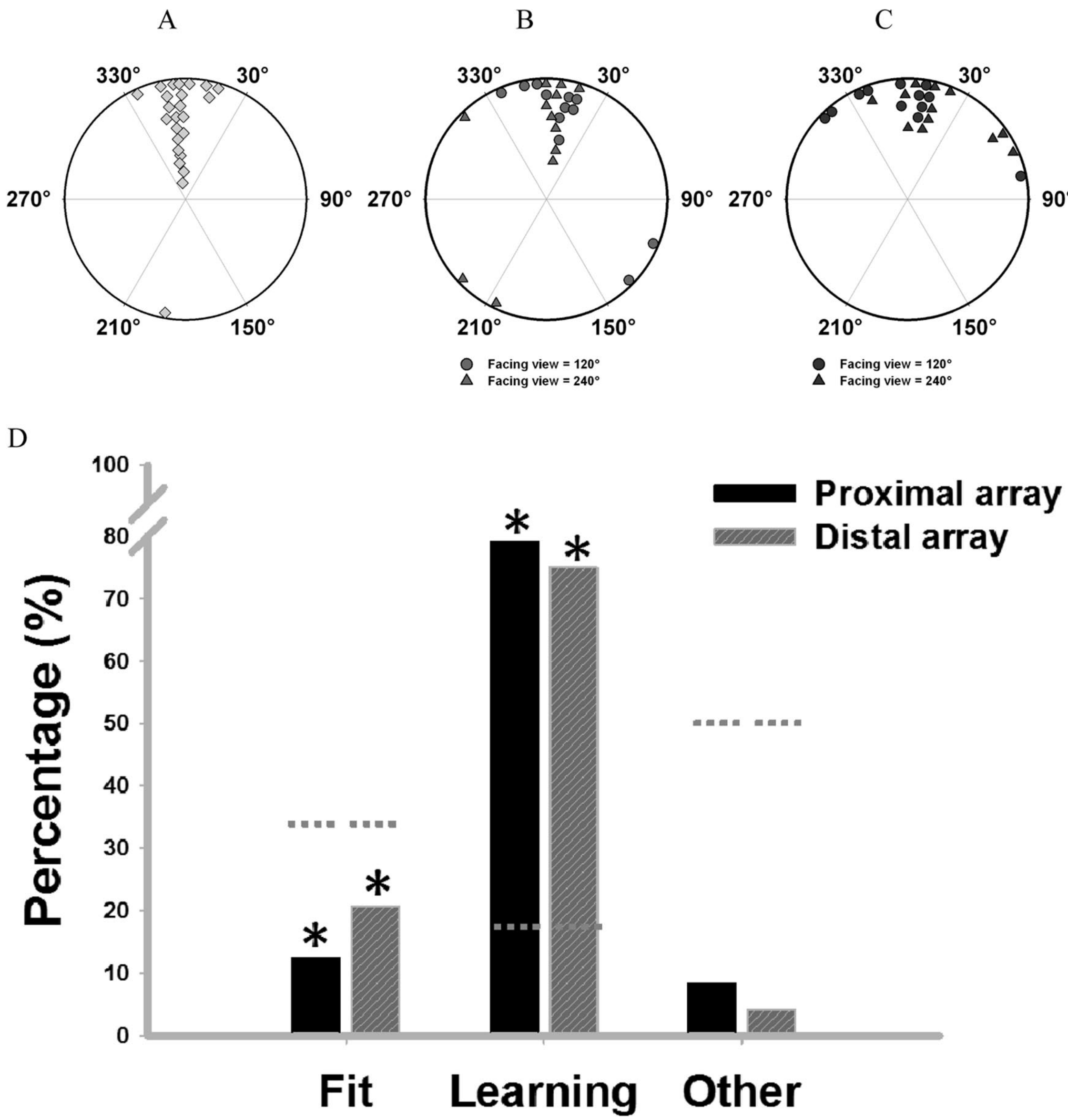

Figure 7. Distribution of the subjective headings in Experiment 4. Panel A shows the distribution for the baseline condition. Panel B shows the distribution for the proximal landmark array condition. Panel C shows the distribution of subjective headings for the distal landmark array condition. Panel D shows the frequency of subjective headings within the fit category (expected heading if orienting cue was used), learning category (expected if participant assumed the same heading as the learning heading), and other (heading not within the fit or learning category) in the two disorientation conditions (proximal array vs. distal array) in Experiment 4. The dotted line in each condition represents the chance level. * $p < .05$.

.001, whereas the frequency of subjective headings within the fit category was four (16.7%) and not significantly different from the chance level (33.3%), ($\chi^2_{\mathrm{Fit}}(1) = 3.00$, $p = .083$. In the distal array condition (see Figures 8C and 8D), the frequency of subject heading in the learning category was eight (33.3%) and significantly greater than chance (16.7%), $\chi^2_{\mathrm{Learning}}(1) = 4.80$, $p = .028$. The frequency of subject heading was 15 (62.5%) in the fit category and significantly greater than chance (33.3%), $\chi^2_{\mathrm{Fit}}(1) = 9.19$, $p = .002$. We also directly compared the frequencies in the fit category of the two visual cues conditions. The frequency of subjective headings in the fit category for the distal array condition was significantly larger than for the proximal array condition (62.5% vs. 16.7%), $\chi^2(1) = 10.54$, $p = .001$.

The results of Experiment 4 and 5 are congruent with the results of Experiments 2 and 3, suggesting that there is no difference whether the cities' directions are learned from a map or from within the immediate environment, whether the cities' directions are indicated by object labels or city labels. Furthermore, the results from Experiments 1, 2, and 4 suggest that

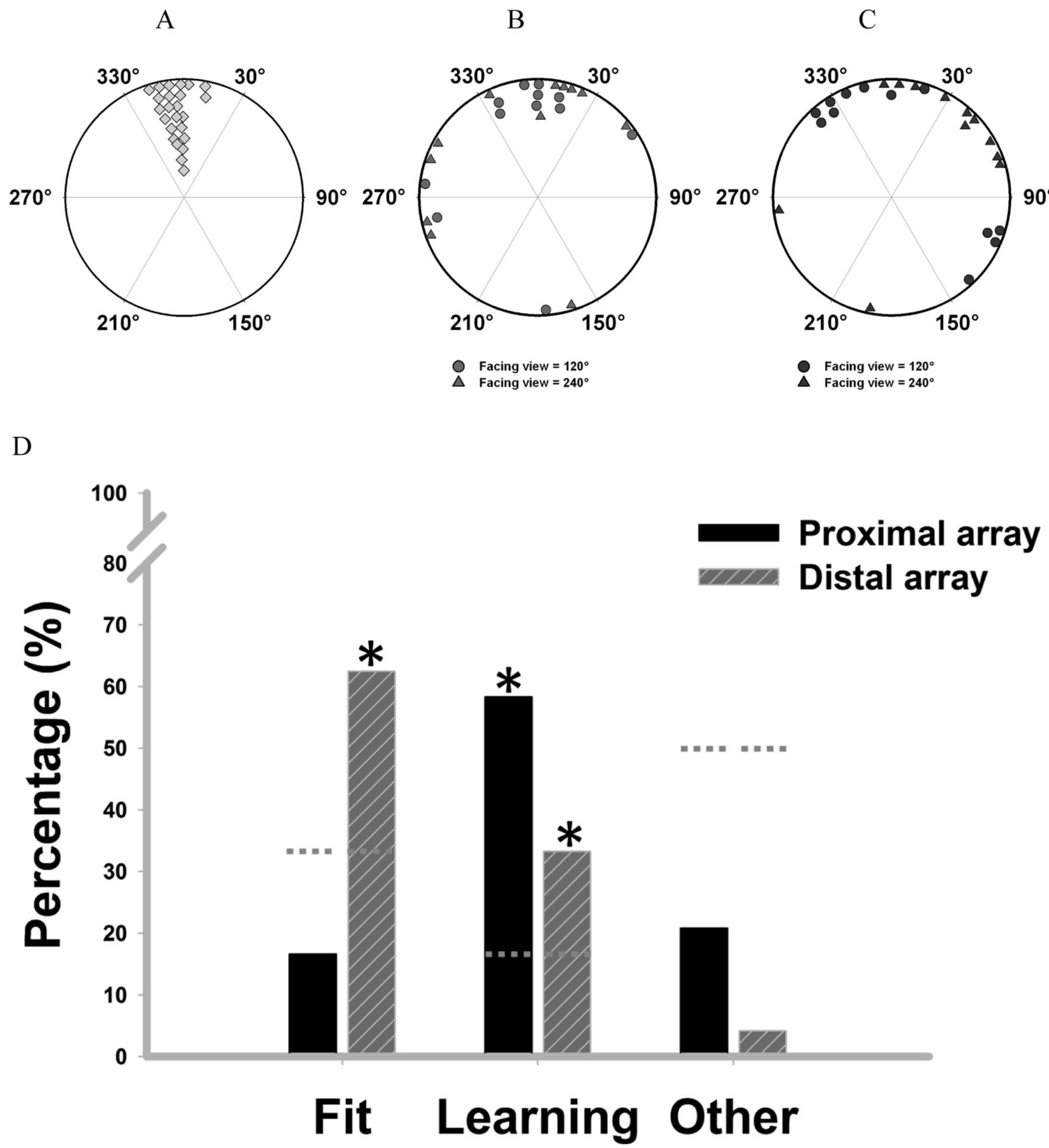

Figure 8. Distribution of the subjective headings in Experiment 5. Panel A shows the distribution for the baseline condition. Panel B shows the distribution for the proximal landmark array condition. Panel C shows the distribution of subjective headings for the distal landmark array condition. Panel D shows the frequency of subjective headings within the fit category (expected heading if orienting cue was used), learning category (expected if participant assumed the same heading as the learning heading), and other (heading not within the fit or learning category) in the two disorientation conditions (proximal array vs. distal array) in Experiment 5. The dotted line in each condition represents the chance level. * $p < .05$.

reorienting to multiple local objects is different from reorienting to remote cities.

General Discussion

Extensive studies have examined roles of different cues in reorientation relative to a local environment. The results showed that human adults could use both shapes of boundaries and shapes of arrays of separate objects in reorientation (Gouteux & Spelke, 2001). However, no study has examined roles of cues in reorientation relative to a broader environment although reorientation relative to a broader environment is a typical reorientation task in daily life. In the current project, we argued that the findings that human adults could use both shapes of boundaries and shapes of arrays of separate objects in reorientation relative to local environments might not be extended to reorientation relative to broader environments. Specifically, we hypothesized that reorientation relative to broader environments would be more challenging than reorientation relative to local environments. Consequently, human adults might use the more salient cue (i.e., shapes of boundaries) but not the less salient cue (i.e., shapes of arrays of separate objects) in reorientation relative to broader environment. The findings of the current experiments support these hypotheses.

The results of Experiments 2, 3, 4, and 5 showed that human adults used a fence-like array but not a four-landmark array in reorientation relative to remote cities. This result was not due to size/distance difference between the fence-like array and the four-landmark array (Lew, 2011) because the distal array of four landmarks and the distal fence-like array had the same distance to the observer. The failure to use the four-landmark array in adults' reorientation in the current study was not consistent with previous findings (Gouteux & Spelke, 2001, but see Reichert & Kelly, 2011). In Gouteux and Spelke's (2001) study, adults could use the shape of an array of four bins to find the correct bin and the rotational bin.

This discrepancy cannot be attributed to the difference in targets' names (city vs. object) or in learning methods (map learning vs. seeing targets in environments, virtual environment vs. real environment) between these two studies. In the current studies, the remote cities were referred to as real cities (Experiment 2) or hypothetical cities using objects' names (Experiment 4). Participants learned the cities by visually perceiving the directions of the hypothetical cities in the immediate environment (Experiment 4) or learned the directions of the cities by reading a map (Experiment 2). Regardless of these variances, participants could not use the four-landmark array to reorient relative to the cities. This discrepancy cannot be due to the procedural and material differences between the current study and the previous study either; for example, a virtual environment was used in the current study, whereas a physical environment was used in the previous study (Gouteux & Spelke, 2001). Experiment 1 of the current study was identical to Experiments 2 and 4, except that the targets were objects in the local environment. The result of Experiment 1 showed that participants could use the four-landmark array to reorient relative to the local environment, replicating the finding in the previous study.

The discrepancy in using separated identical landmarks for reorientation between Experiments 2 and 4 of the current study and the previous study (Gouteux & Spelke, 2001) might be due to the different environments relative to which participants needed to reorient between these two studies. In particular, participants needed to reorient relative to a broader environment in Experiments 2 and 4 of the current study, whereas participants needed to reorient relative to a local environment in the previous study (Gouteux & Spelke, 2001). There are two important differences between reorientation relative to a local environment and reorientation relative to a broader environment that might cause the discrepancy.

First, reorientation relative to broader environments is more challenging than reorientation relative to the immediate local environment as the visual information available in the local immediate environment provides more accessible orientation cues for the local environment than for the broader environment. It has been demonstrated that human adults could not use distinctive feature cues in reorientation in a more challenging task. Adults did not use a distinctive feature to reorient when they were simultaneously conducting a secondary task (e.g., Hermer-Vazquez et al., 1999; Ratliff & Newcombe, 2008) although they could use a distinctive feature in reorientation without the interference of a secondary task (e.g., Hermer & Spelke, 1996). Because the current study used a more challenging task than did Gouteux and Spelke's (2001) study, the shape of the four-landmark array, analogous to a distinctive feature, might be an ineffective reorientation cue in the current study but an effective reorientation cue in Gouteux and Spelke's study (see also Bodily et al., 2013). Second, attention was exclusively allocated to the local environment (i.e., the bins on the floor) in a goal localization task of Gouteux and Spelke's study but primarily allocated to the broader environment in the spatial orientation task in the current study. Participants paid attention to the bins on the floor to encode the correct bin in Gouteux and Spelke's study. Hence, they might also pay attention to the relations among different bins. Participants in Experiments 2 and 4 of the current study primarily paid attention to the directions of the cities and were not attempting to remember any locations in the local environment. Hence, the shape of the landmark array might not be perceived or represented because perceiving the shape of a landmark array requires mental efforts (e.g., Wang & Spelke, 2000). This speculation is underscored by the fact that participants could not see any two landmarks (i.e., poles) in the four-landmark array from a single viewpoint. In the current project, the projected field of view in the virtual reality system was 49° horizontally. The subtended angle between the two poles on the short edge of the rectangle to the learning position was 52° and larger than the projected field of view. Hence, participants could not see any of the two poles at one single viewpoint in the learning position.

However, participants could use a fence-like landmark array in reorientation relative to cities. When 32 poles were added to each edge of the rectangular shape of the pole array, participants used this landmark array in reorientation relative to cities (Experiments 3 and 5). There are two explanations for the superiority of the fence-like array to the four-landmark array in reorientation relative to cities. These two explanations correspond to the two prevailing theories in the reorientation literature.

First, people might perceive the fence-like array as a functional boundary instead of an object array (Pecchia & Vallortigara, 2012). According to the geometric module theory, a 3D enclosure could invoke the geometric module (Lee & Spelke, 2010), which facilitated reorientation. To explain the current findings, the geometric module theory might need some elaborations. Although the current format of the theory does not explicitly stipulate that a 3D enclosure requires a continuous extended surface, some findings have suggested so. For example, children could effectively locate targets using the extended short walls (3D continuous surfaces) connecting the bins but not the separate corners placed together with the bins (e.g., Gouteux & Spelke, 2001, Experiments 7 and 8). Studies using functional magnetic resonance imaging revealed that hippocampal activity in human adults increased when the number of extended surfaces increased but not when the number of separate landmarks increased (Bird, Capponi, King, Doeller, & Burgess, 2010). However, the current findings indicate that in order to invoke the geometric module, a continuous extensive surface is not essential because the poles in Experiments 3 and 5 were still disconnected from each other (e.g., ~13 cm between two poles on the longer side). Interestingly, the ~13-cm gap still impaired participants' movement through it; further studies need to investigate whether participants would still use a fence-like object array in reorientation when a gap between two adjacent poles is large enough to allow people to walk through it easily (Bird et al., 2010; Learmonth, Newcombe, Sheridan, & Jones, 2008).

Second, it is easier for participants perceive the shape of the fence-like landmark array than the shape of the four-landmark array, and no geometric module is required. According to the adaptive combination theory for reorientation (Lew, 2011; Newcombe & Ratliff, 2007), all perceptible cues that mathematically specify directions in the environment can be used for reorientation, and the relative importance of the cues depends on the experienced reliability and salience of the cues. This proposal was supported by the findings that people could use a distal landmark or a distal landmark array as a directional cue (see Lew, 2011, for a review). The fence-like landmark array in Experiments 3 and 5 in the current study had 34 poles on each edge. Hence, participants might readily perceive the shape of the landmark array. In contrast, the four-landmark array in Experiments 2 and 4 had two poles on each edge; participants might need efforts to group them together and then perceive the shape of the array. Hence, it is easier to perceive the shape of the fence-like landmark array than the shape of the four-landmark array. Therefore, it is easier to use the fence-like landmark array in reorientation relative to a broader environment.

It is important to note that both theories can explain the current findings with some elaborations. Although the current findings could not unambiguously dissociate between these two theories, the current findings indicate that a shape of an object array and a shape of an enclosed boundary might be quantitative rather than qualitative in reorientation. When the number of the objects in the array increases, an object array could function as an enclosed boundary in reorientation. Furthermore, together with the previous studies, the current study clearly demonstrated that use of a cue in reorientation is a function of many variables including mental capacity, environment (local vs. remote), and cue salience. In particular, participants with higher mental capacity (e.g., adults) are more likely use local cues in reorientation compared to participants with lower mental capacity (e.g., toddler). Participants are more likely to use local cues in reorientation relative to local environments than relative to remote environments. Participants are more likely to use a local cue with a more salient shape than a local cue with a lower salient shape. Furthermore, the cue salience might also be modulated by distance of the cue. In particular, in Experiment 1 of the current study, the proximal landmark array could not be used in reorientation, whereas the distal landmark array could be used in reorientation. Any model of human reorientation should accommodate these findings.

We acknowledge that in the current study, participants were not required explicitly to remember the shape of the landmark array, although they were required to point to the corners of the array of landmarks before they learned the directions of the cities. Hence the superiority of the fence-like array to the four-landmark array in Experiments 2–5 might not extend to conditions in which participants are explicitly required to remember the locations of corners of the object array. Wang and Spelke (2000) argued that human adults might not encode interobject spatial relations but encode the intercorner spatial relations. However, Sluzenski and McNamara (2011; see also Mou et al., 2006) reported that participants also encoded interobject spatial relations when they were asked to learn objects' locations, at least when the object array formed a regular shape. A future study is required to investigate whether people can use a four-landmark array to reorient after they are explicitly asked to learn the locations of the landmarks before they learn the directions of the cities.

We acknowledge that, in addition to the shape that might have been highlighted by the fence-like array, other local features in the fence-like array may indicate some orientation information. For example, the difference in the gap widths between long and short sides might have provided some orientation cues and might have facilitated orientation in the fence-like arrays. Further studies are required to test this possibility.

Last but not least, in Wang and Spelke (2000), participants could be reoriented by a polarized light after disorientation. However, in the current study, participants could not reorient with respect to remote cities by four separated landmarks. The reason for this discrepancy is not clear. One possible reason could be that the single light produced a detectable brightness gradient that provided unique directional information as a single landmark but the four identical landmarks could not indicate a unique direction unless their shape could be encoded. The other possibility is that the light might be encoded to be part of the boundary as it was mounted on the boundary. Hence, it could be used in reorientation just as the objects that were placed close to the boundary (Lee & Spelke, 2010; Lew et al., 2010).

In conclusion, this project studied human adults' reorientation to local and broader environments. The results indicated that participants used the shape of a four-landmark array in reorientation relative to the local environment but not relative to the broader environment. The results also indicated that human adults more readily used the shape of a fence-like object array than a four-landmark array in reorientation to broader environments. These results suggest that reorientation relative to a broader environment is more challenging and hence requires more salient orientation cues in the local environment.

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