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Describing spatial locations from perception and memory: The influence of intrinsic axes on reference object selection

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ABSTRACT

A target object's location within a configuration of objects can be described by spatially relating it to a reference object that is selected from among its neighbors, with a preference for reference objects that are spatially close and aligned with the target. In the spatial memory literature, these properties of alignment and proximity are defined with respect to a set of intrinsic axes that organizes the configuration of objects. The current study assesses whether the intrinsic axes used to encode a display influences reference object selection in a spatial description task. In Experiments 1–4, participants selected reference objects from displays that were perceptually available or retrieved from memory. There was a significant bias to select reference objects consistent with the intrinsic axes used to organize the displays. In Experiment 5, participants learned the display from one viewpoint, but described it from another viewpoint. Both viewpoints influenced reference object selection. Across experiments, these results suggest that the spatial features underlying reference object selection are the intrinsic axes used to encode the displays.

Introduction

When people describe the location of an object, they often spatially relate it to one of the many surrounding objects in the environment. For example, imagine that your spouse is looking for his or her sunglasses, and you know that they are on the kitchen counter. How would you describe their location? Kitchen counters often contain many objects, and therefore there are many candidate reference objects. You could use the spatial description "Your sunglasses are in front of the microwave," with the sunglasses as the located object and the microwave as the reference object. Alternatively, you could describe their location with respect to other reference objects, such as "by the coffee pot" or "next to the phone." It is typically assumed that a reference object is selected on the basis of properties such as perceptual, conceptual and/or spatial features that make it salient relative to other surrounding objects, and therefore easy to find (e.g., De Vega, Rodrigo, Ato, Dehn, & Barquero, 2002; Miller & Johnson-Laird, 1976; Talmy, 1983). In the sunglasses example, the microwave may be considered perceptually salient because of its large size. In contrast, the phone may be considered conceptually salient, because you just hung up from a phone call. Finally, the coffee pot may be considered spatially salient because its position on the counter is vertically or horizontally aligned with the sunglasses in terms of the viewing perspective.

Among these different salience dimensions, previous research has shown that the spatial features between the located object and the candidate reference objects play a central role in reference object selection (Carlson & Hill, 2008; Craton, Elicker, Plumert, & Pick, 1990; Hund & Plumert, 2007; Miller & Carlson, 2011; Miller, Carlson, & Hill, 2011). For example, Hund and Plumert (2007) found an influence of proximity, such that objects that were closer to the located object were preferred as reference objects.

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Carlson and colleagues (Carlson & Hill, 2008; Miller et al., 2011) found a preference for reference objects that were aligned with the located object, occurring in an on-axis placement that was in a vertical or horizontal direction rather than in an off-axis placement that was in a diagonal direction. Moreover, when these dimensions were directly contrasted, the spatial features were prioritized over perceptual features such as color and over conceptual features such as the functional relations between the two objects. To illustrate, Miller et al. (2011) compared the influence of spatial and perceptual features on reference object selection. Participants were shown scenes containing a located object, two candidate reference objects placed around and at the same distance from the located object, and two distractor objects placed farther away. The spatial features of the candidate reference objects were manipulated, such that one was placed vertically aligned with the located object (on-axis, a preferred location, Hayward & Tarr, 1995; Logan & Sadler, 1996), and the other was placed in an diagonal direction (off-axis) with respect to the located object. The perceptual features were also manipulated, such that one candidate reference object was uniquely colored within the display, and the other candidate reference object shared its color with the located object and the distractors. These features (spatial: on-axis/off-axis and color: unique/shared) were crossed across displays. The key finding was a strong preference for aligned on-axis reference objects, with no influence of whether the objects were perceptually unique.

In the current paper, we extend this work on the importance of spatial features in reference object selection in two directions. First, we link these spatial features of proximity and alignment to the concept of a spatial reference direction (Mou & McNamara, 2002), which corresponds to a preferred organization of a configuration of objects according to a set of intrinsic axes. Second, we examine the influence of these intrinsic axes on reference object selection across three conditions: *perceptual*, *memory*, and *changed perspective*. For the perceptual condition, we consider a situation in which a reference object must be selected from a configuration of objects that are currently in view. In the sunglasses example, this would be analogous to indicating the location of the sunglasses to a person standing in the kitchen who is searching for them on the counters in front of them. The prior work on reference object selection has focused on this type of perceptual situation.

However, we often need to select reference objects in other situations, such as recalling the objects from memory or when viewing the objects from different perspectives over time. Accordingly, for the memory condition, we consider the situation in which a configuration of objects is initially learned, and a reference object must be selected from that configuration from memory at a later point in time when the objects are not perceptually available. In the sunglasses example, this would be analogous to standing in the living room in your house, and describing the location of the sunglasses that are on the counter in the kitchen.

Finally, for the changed perspective condition, we consider the situation in which a configuration of objects is learned from a given perspective, and then a reference object must be selected from this configuration when viewed from a different perspective. In the sunglasses example, this would be analogous to describing the location of the sunglasses when standing at the backdoor – a location that offers a different viewpoint from the one in which you noticed the sunglasses while at the counter in the kitchen.

Spatial reference direction and intrinsic axes

The spatial features of proximity and alignment that have been identified in previous work as being important for reference object selection can be interpreted with respect to the concept of a *spatial reference direction* that comes from the spatial memory literature (Mou & McNamara, 2002). A spatial reference direction corresponds to a set of axes that are imposed on an array of objects that can then be used to define their spatial relationships, much like cardinal directions such as north and east can be applied to large scale places to encode geographic knowledge. These axes are referred to as intrinsic axes, because once applied to the configuration, they effectively assign directions to the configuration (much like assigning top, bottom, left and right sides to an object, or applying cardinal directions, such as north side, west side, and so on). Importantly, the intrinsic axes may adopt their orientation from different sources of information, such as the layout of the objects, environmental properties including the shape of the room or the table upon which the objects are located, or the perspective of the viewer. For example, Fig. 1, Panel A shows a display of seven objects with a set of intrinsic axes (in white) imposed on the configuration. The spatial reference direction that corresponds to this orientation of intrinsic axes could be adopted based on the symmetric axis of the layout (Greenauer & Waller, 2010; Mou, Liu, & McNamara, 2009; Mou & McNamara, 2002), the orientations of the individual objects (Marchette & Shelton, 2010), the rectangular dimensions of the table (Mou, Xiao, & McNamara, 2008; Shelton & McNamara, 2001), or the viewing perspective of a person (Greenauer & Waller, 2008; Shelton & McNamara, 2001) standing at the front of the table at the position labeled with 0°. In Panel A, these sources all orient the axes in the same way. Alternatively, the viewing perspective could be changed to the position at 315° as shown in Panel B. In this panel we show a set of intrinsic axes that are based on the spatial reference direction defined by this viewing perspective; note that this is at odds with the orientation of the axes based on the symmetric axis of the layout and the rectangular dimensions of the table, which would both orient the axes as in Panel A. Finally, Fig. 1, Panel C shows a configuration in which the orientation of the objects and the viewpoint at 315° both correspond to a spatial reference direction with the intrinsic axes defined as in Panel B, whereas the rectangular table and the viewpoint at 0° both correspond to a spatial reference direction with the intrinsic axes defined as in Panel A. These three panels illustrate the idea that there may be correspondence and conflict among these different sources of information. Throughout, we will use the term spatial reference direction to refer to the application of a given set of intrinsic axes to the configuration, oriented with respect to a given source of information (e.g., layout, object orientation, environmental features, viewing perspective).

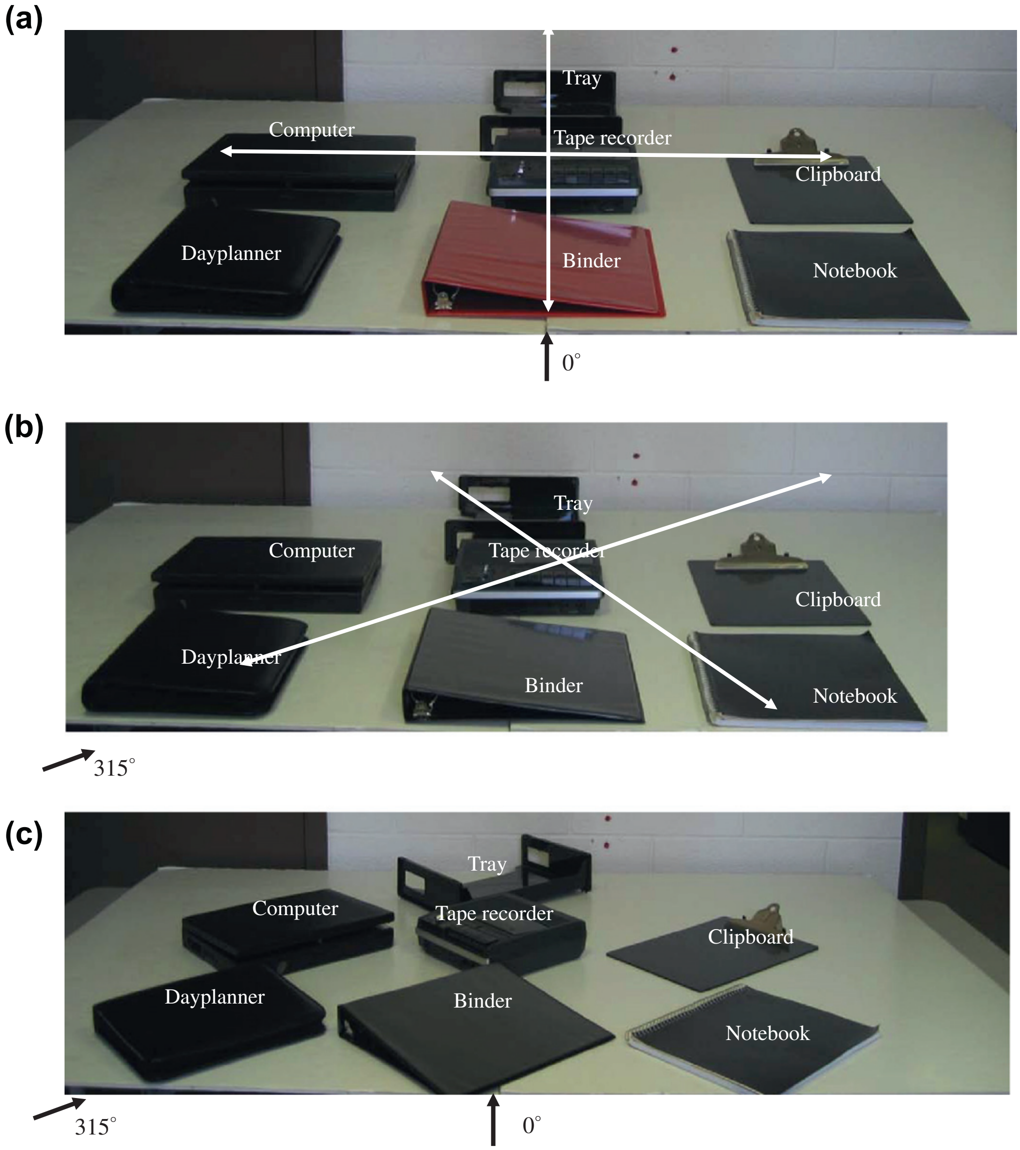

Fig. 1. Panels A–C show sample learning layouts for Experiments 1 and 2. In Panel A, the intrinsic axes are oriented according to the symmetric axis of the layout, the orientations of the individual objects, the rectangular dimensions of the table, and the viewing perspective of a person at 0°; these sources of information are all aligned in this panel. Because the binder is red, this panel also illustrates the uniquely colored condition. In Panel B, the intrinsic axes are oriented according to the viewing position of 315°, which is in conflict with the other sources of information that establish the intrinsic axes as in Panel A. Because the binder is black, this panel also illustrates the uniformly colored condition. In Panel C, the objects are oriented in alignment with a spatial reference direction established by a viewing perspective at 315°, which is misaligned with a spatial reference direction established by the rectangular dimensions of the table and a viewing perspective at 0°. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The standard task used to identify the spatial reference direction that orients the intrinsic axes is the judgment of relative direction (JRD) task. In this task, subjects first learn a display of objects from a given perspective. Subjects are then relocated so that the display is no longer visible, and are given instructions telling them to imagine standing at a specific location within the display at an imaginary heading, and then asked to point to a third object. An example instruction using Fig. 1, Panel A would be: "Imagine you are at the day planner, facing the computer. Point to the binder". The first two objects (day planner and computer) establish the imagined standing location and heading direction, and the third object (binder) serves as the target at which they are instructed to point. The main dependent variables are the response time and error for pointing to this target, plotted as a function of the imagined heading. The key finding across numerous studies is that response times are fastest and errors are lowest when the imagined heading is aligned with the spatial reference direction with which the subject learned the display (e.g., Greenauer &

Waller, 2008, 2010; Mou & McNamara, 2002; Mou et al., 2009). For example, in Fig. 1, if participants are instructed to encode the display relative to their viewing perspective at 0°, pointing responses to objects that are organized by intrinsic axes aligned to this perspective (for example, imagine you are at day planner, facing the binder) are faster and more accurate than to objects that are not aligned with these axes (for example, imagine you are the day planner, facing the tape recorder). This robust pattern of faster and more accurate responses to objects aligned with the axes can be used to diagnose the spatial reference direction in ambiguous contexts in which there is competition among the possible sources for establishing the intrinsic axes (as in Panel C), and subjects are not explicitly told which spatial reference direction to use.

Importantly, note that these preferred object locations that are aligned with the intrinsic axes of the spatial reference direction are also closer than the objects that fall off-axis. Thus, the spatial features of alignment and proximity that we see operating within reference object selection in a linguistic task may be due to a reliance on the spatial reference direction that is used to encode the display. The current study offers a test of this hypothesis.

Applying spatial reference directions to reference object selection

With respect to the spatial reference direction, the preferred object locations are ones that are both closer and aligned with the intrinsic axes. Proximity and alignment are also features that are prioritized for reference object selection. This similarity in the use of spatial features across these two domains may reflect a tight connection between the way in which a display is organized, and the way in which the display is spatially described. The goal of the current paper is to systematically assess this connection. If the spatial reference direction with which a spatial layout is organized is an integral part of the way in which it is represented, then there should be a bias to select reference objects for target that are aligned with the intrinsic axes. This hypothesis is consistent with Taylor and Tversky (1992a) who showed that the perspective used to learn a map influenced both the way in which participants described the environment, and the way in which they later redrew the map. Moreover, Taylor, Naylor, and Chechile (1999) found that the perspective preserved in memory influences the way people retrieve information. They compared the accessibility of spatial knowledge when participants learned an environment by navigating using a route perspective or by studying a map using a survey perspective. Participants who learned from a route perspective performed better on route perspective tasks, such as a route description task and a route distance estimation task. In contrast, participants who learned from a survey perspective performed better on survey perspective tasks, such as a walk-through-the-wall task that involved constructing short-cut routes and a Euclidean distance estimation task.

However, this connection between encoding and describing may not be obligatory (Philbeck, Sargent, Arthur, & Dopkins, 2008; Wang, 2004). For example, Wang (2004) found strong alignment effects reflecting the encoding of particular inter-object relations within a JRD pointing task, but no such effects when participants performed the same task but verbally reported the direction of the target rather than pointed. This result indicates that the linguistic system may not be confined to the perspective employed in JRD task. More recently, Philbeck et al. (2008) showed that different reference frames underlying the pointing task and the verbal report task were the cause of the dissociation across the two tasks that was observed by Wang (2004). Such possible independence between encoding and describing is also consistent with other work by Taylor and Tversky (1992b) that shows equivalent response time and accuracy performance on verifying survey and route questions about an environment, regardless of the perspective used to learn that environment.[1]

Reference object selection within perception, memory, and changed perspective conditions

The research showing prioritization of the spatial features of proximity and alignment on reference object selection has been conducted using displays of objects that are perceptually available during the reference object selection task. In a typical reference object selection task, a participant is presented with a display of objects, the experimenter provides a prompt such as “Where is the <located object>?” and the participant responds by filling in a sentence frame “<The located object> is ________”. Sometimes the spatial term is included in the sentence frame (for example, “<The located object> is by the _______”) and sometimes the participant provides the spatial term. In both cases, the primary dependent variable is the reference object that the participant selects.

The current paper starts with the observation that a spatial reference direction may be used in this perceptual condition to organize the display of objects, and asks whether this organization may bias reference object selection. We assessed this in Experiments 1 and 2, asking participants to select reference objects while viewing displays whose configurations were organized with particular spatial reference directions, as established by previous research. The critical question was whether participants would be biased to select reference objects consistent with the expected spatial reference direction. Because in these experiments the perceptual available displays were described without first being learned, we could not collect JRD data to verify the intrinsic axes that were used to organize the displays during perception. To countermand this limitation, we used a layout of objects (see Fig. 1, Panel A) that has been used in extensive previous research that clearly establishes that the intrinsic axes are organized by the display’s geometric structure (Mou & McNamara, 2002; Mou, Fan, McNamara, & Owen, 2008; Mou et al., 2009). In addition, we included manipulations of viewing perspective (as in Fig. 1, Panel B) and object orientation (as in Fig. 1, Panel C) to further

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[1] The disparity in the results across the research by Taylor and her colleagues (1992a), Taylor and her colleagues (1992b, 1999) might due to different learning processes as discussed in Taylor et al. (1999).

establish that the organization was based on the geometric structure of the display.

In Experiments 3 and 4 we tested for a link between the organization of the display and the selection of a reference object when the objects must be retrieved from memory. In these memory conditions, we asked participants to learn an array of objects, and we verified the spatial reference direction with which they organized the display using a judgment of relative direction (JRD) task. This was followed by a reference object selection task that required participants to rely on their memory for the display of objects. The critical question was whether participants would be biased to select reference objects consistent with the organization with which they learned the display, as reflected in the JRD data.

Experiments 1–4 offer straightforward tests of the connection between the organization of the display and the selection of a reference object, and the data across all of these experiments show a significant correspondence. In Experiment 5, we explored a more complicated situation. Specifically, participants learned a display from an initial perspective, and we again verified the organization with which it was learned using a JRD task. We then presented the display to participants from a different perspective for the reference object selection task. In this way, we set up a competition between the representation of the display in memory and the organization derived from the currently perceptually available information. The critical question was whether participants would rely on the organization from memory, the organization that was perceptually available or some combination of these perspectives. Previous research has suggested conflicting results. Some research has shown a preference for an initial learned perspective over a novel perceptual perspective (Shelton & McNamara, 2001). Other research has shown a preference for the current perspective over the perspective retrieved from memory (Waller, Montello, Richardson, & Hegarty, 2002; see also Farrell & Robertson, 1998; Rieser, 1989). Finally, there is also some evidence for a combination of different perspectives (Carlson-Radvansky & Logan, 1997). Thus, together with Experiments 1–4, Experiment 5 was designed to bring clarity to the relative contributions of the perceptual display vs. the memory representation for reference object selection.

Experiment 1

The primary goal of Experiment 1 was to determine whether reference object selection for a perceptually available display would be influenced by the spatial reference direction that is used to organize the configuration of objects during viewing, as predicted based on prior memory research. Specifically, participants stood in front of a configuration of objects using the layout structure from Mou and McNamara (2002). As can be seen in Fig. 1, Panel A, this layout structure presents the objects with an intrinsic axis parallel to the direction of 0°, and the findings by Mou and McNamara (2002) (see also Mou et al., 2008; Mou et al., 2009) indicate a strong bias to define the spatial reference direction based on the symmetric axes oriented at 0–180° and 90–270°. This means, for example, that participants would be more likely to represent the binder with respect to the tape recorder (aligned with the 0–180° axis) or with respect to the notebook (aligned with the 90–270° axis) than with respect to the clipboard (misaligned, not along an axis). We assessed in Experiment 1 whether such bias for encoding these inter-object relations translated into a bias for selecting reference objects that also fell along these axes.

We also included two manipulations that were crossed to further establish that the organization applied to the display when perceptually available was indeed based on the intrinsic axes oriented with respect to the geometric structure of the display. First, as indicated in Fig. 1, Panel B, we manipulated whether participants viewed the displays from a perspective that was aligned with the preferred spatial reference direction (0°) or misaligned (315°, labeled counterclockwise from the 0°). As addressed in the Introduction, several factors may compete in defining the spatial reference directions in the current layout, including the orientations of the objects, the viewing perspective, the structure of the layout and the rectangular table as an external background. However, based on previous research, we expected the structure of the layout and the external background (i.e., table orientation) to override the viewing perspective (e.g., Greenauer & Waller, 2010; Mou & McNamara, 2002; Mou et al., 2009); thus, for both viewing perspectives of 0° and 315° we expected participants to organize the display according to the intrinsic axes shown in Fig. 1, Panel A. Second, we manipulated the orientation of the objects in the display, so that their orientation was consistent with a viewing perspective from 315°, as shown in Fig. 1, Panel C. Note, however, that the symmetric axis parallel to the direction of 0° is still available and is also encouraged by the rectangular table. Past work (Li, Mou, & McNamara, 2009; Mou et al., 2008) has shown that the environmental features of the table and room are strong determinants of the preferred spatial reference direction. Accordingly, we expected that these conditions would also show the same preferred spatial reference direction as illustrated in Fig. 1, Panel A. In all cases, the critical question was whether this spatial reference direction would influence reference object selection.

Finally, we included an additional manipulation of perceptual salience, in which for some participants, the binder was uniquely colored (red among all other black objects; compare Fig. 1, Panels A and B). This manipulation offered a final strong test to the work by Carlson and Hill (2008) and Miller et al. (2011) that has consistently observed no bias in reference object selection for perceptually salient objects.

In all, there were 8 conditions manipulated between subjects, arising from a factorial combination of viewing perspective (0° and 315°), orientation of the objects in the display (0° and 315°) and perceptual salience (binder was red or black). Each participant received one of these conditions. Within each condition, there were 7 trials devised so that each object in the display served as the located object. On each trial, the experimenter provided the prompt "The <located object> is by the _____" and the participant responded by selecting a reference object in the display. The order of the objects serving as located objects was randomized for each participant. Fourteen configurations were used that counterbalanced with a Latin Square the assignment of objects to positions in the display. For example, for some participants the binder was located as in Fig. 1; for other participants, it was at the location of the dayplanner, and so on. We included the spatial preposition "by" because it can apply to any of the objects close to a given located object, without a bias toward a particular location (Logan & Sadler, 1996; Miller et al., 2011).

Method

Participants

One hundred and twelve undergraduates from the University of Notre Dame participated in exchange for partial course credit.

Materials

The layout consisted of the same configuration of seven objects as Mou and McNamara (2002) (see Fig. 1; labels identifying the objects are provided in the figure but were not available to participants). All objects were selected with the restrictions that they had the same color and general shape and were in the same semantic category (office supplies). The objects were: binder, clipboard, dayplanner, laptop, notebook, tape recorder, and tray. The layout was placed on and aligned with a rectangular table. Fourteen different configurations of learning displays were created using a Latin square and were balanced across participants, such that a given object was not in the same position across displays.

Perceptual features were manipulated using two types of displays. In the uniformly colored displays, all objects were black, and thus no object stood out due to perceptual features, given that size and shape were also generally controlled (see Fig. 1, Panel B). In the uniquely colored displays, the binder was red and the other six objects were black (see Fig. 1, Panel A), with the binder's location occurring at each of the seven locations across participants.

Spatial features were manipulated by (1) varying the viewing perspective, with some participants standing at 0° and others at 315°; and (2) object orientation, with some objects oriented to be aligned with 0° and others oriented to be aligned with 315°. These two factors were factorially combined. In all, the design consisted of the following between subject variables: color of the display (unique vs. uniform) × viewing perspective (0° vs. 315°) × object orientation (0° vs. 315 °).

Participants performed a reference object selection task. On each trial, the experimenter indicated an object from the display to serve as the target, and the participant selected a reference object from the display to complete the frame "The target is by the _____". Each object in the display served as the target once, yielding 7 trials for each participant, presented in a random order.

Procedure

Participants were led to a given viewpoint (0° or 315°) with their eyes closed. Once they were in position, participants opened their eyes and were asked to point to each object as it was named by the experimenter. This procedure ensured that participants could correctly identify each object's name and location. The order in which objects were named corresponded to the columns aligned with the participant's viewing direction (0° or 315°). After becoming familiar with all the objects, participants were asked to verbally describe the location of the objects within the scene while maintaining their given viewing perspective. They were prompted with statements of the form "Where is the <target>?" and were told to respond using the frame "The <target> is by the _____", selecting any object in the display to serve as the reference object.

Results and discussion

Previous research (e.g., Greenauer & Waller, 2010; Mou & McNamara, 2002; Mou et al., 2009) has suggested that the preferred spatial reference direction should be defined by the internal structure of the display based on the symmetric axes running from 0–180° and 90–270°, despite other factors that encourage a different orientation. Accordingly, we predicted that for both learning perspective groups and for both object orientation groups, the intrinsic axes would be oriented in this manner. To assess whether this organization was used as the basis for reference object selection, we coded each reference object that was selected in the reference object selection task, using the following categories: *aligned axes* (the selected reference object and the located object fell along the 0–180° or 90–270° axes); *misaligned axes* (the selected reference object and the located object fell along oblique axes of 45–225° and 130–315°); and other (the selected reference object and the located object fell along axes of 27–207°, 63–252°, 153–333°, 117–297°). For example, for the display in Fig. 1, Panel A, if the dayplanner was the located object and the participant selected the computer or the binder as the reference object ("The dayplanner is by the computer/binder"), these responses would be coded as aligned axes; if the participant selected the tape recorder, that response would be coded as misaligned axes; and if the participant selected the clipboard, that response would be coded as other. These codes would be the same, regardless of whether the viewing perspective was 0° or 315°.

Observed frequencies, a priori frequencies and expected frequencies for selecting reference objects among these three categories, summed across participants and conditions, are presented in Table 1. There are 42 possible a priori choices (from each of the seven objects to all of the other objects) distributed as follows across the three categories: 22 for aligned axes, 12 for misaligned axes and 8 for other axes. The expected frequency of reference object selection for each category was equal to the sum of the observed frequency multiplied by the a priori proportion of reference object selection along the corresponding type of axes. In Table 1, the pattern of data is clear: a larger observed frequency than expected for the aligned axes category and smaller observed frequencies than expected for the misaligned axes and other categories. Because the observed frequencies are dependent, we tested only the aligned axes category, and a binomial test showed that the observed frequency was significantly larger than the expected

Table 1
The observed frequencies (in bold), a priori frequencies (normal font) and expected frequencies (in italics) for reference object selection across aligned axes, misaligned axes and other axes categories for Experiments 1–5.

Experiments	Aligned axes	Misaligned axes	Other
Experiment 1	(0–180° and 90–270°)	(45–225° and 135°–315°)	27–207°, 63–252°, 153–333° and 117–297°
Observed frequency	**756**[?]	**24**	**4**
A priori frequency	22	12	8
Expected frequency	*411*	*224*	*149*
Experiment 2	(0–180° and 90–270°)	(45–225° and 135–315°)	(27–207°, 63–252°, 153–333° and 117–297°)
Observed frequency	**477**[?]	**12**	**1**
A priori frequency	22	12	8
Expected frequency	*257*	*140*	*93*
Experiment 3	(0–180°)	(60–240°)	(120–300°)
Observed frequency	**73**[?]	**20**	**19**
A priori frequency	8	8	8
Expected frequency	37	37	37
Experiment 4	(60–240°)	(0–180°)	(120–300°)
Observed frequency	**59**[?]	**27**	**26**
A priori frequency	8	8	8
Expected frequency	37	37	37
Experiment 5, memory, learning from 0°	(0–180°)	(60–240°)	(120–300°)
Observed frequency	**24**[?]	**19**	**13**
A priori frequency	6	8	8
Expected frequency	*15*	*20*	*20*
Experiment 5, memory, learning from 240°	(60–240°)	(0–180°)	(120–300°)
Observed frequency	**36**[?]	**7**	**13**
A priori frequency	6	8	8
Expected frequency	*15*	*20*	*20*
Mean observed frequency	30[?]	13	13
Experiment 5, changed perspective, learning from 0°	(0–180°)	(60–240°)	(120–300°)
Observed frequency	**12**	**24**	**20**
A priori frequency	6	8	8
Expected frequency	*15*	*20*	*20*
Experiment 5, changed perspective, learning from 240°	(60–240°)	(0–180°)	(120–300°)
Observed frequency	**26**	**18**	**12**
A priori frequency	8	6	8
Expected frequency	*20*	*15*	*20*
Mean observed frequency	19	21	16

[?] Indicates that the observed frequency is significantly higher than the expected frequency by binomial tests, $p < .05$.

frequency ($p < .01$), suggesting a bias to select reference objects consistent with the assumed spatial reference direction.[2]

In addition, we assessed the effects of object salience (color in display: uniform vs. unique), viewing perspective (0° vs. 315°) and object orientation (0° vs. 315°) across the three categories using chi-squared tests. Analyses revealed that there was no difference in observed frequencies across the categories of axes for uniformly colored vs. uniquely colored displays, $\chi^2(2) = 1.25$, $p = .46$, no significant difference due to viewing perspective (0° vs. 315°), $\chi^2(2) = 1.20$, $p = .45$ and no difference due to object orientation (0° vs. 315°), $\chi^2(2) = 1.20$, $p = .45$. Together, these analyses suggest a robustness to the use of a spatial reference direction based on the symmetric axes of the display, the orientation of the table and the structure of the room.[3]

Finally, we conducted a number of subsidiary analyses to evaluate whether there were any independent influences of perceptual salience, object identity or object location within the display on reference object selection, using binomial tests on the proportions. With respect to perceptual features, we computed how often the binder was selected

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[2] A reviewer suggested that the preference for selecting reference objects on the aligned axes could be explained by foreshortening. According to this hypothesis, in Experiments 1 and 2 objects along the vertical aligned axes may have appeared to be physically closer than objects along the horizontal aligned axes, and this may have accounted for the observed pattern of data. This hypothesis would mean that reference objects on the vertical axes would be preferred over reference objects on the horizontal axes, and that the selection of reference objects on the horizontal axes should not differ than chance. However, further analyses showed no significant bias for vertically over horizontally aligned objects, and the objects on the horizontal axis were selected significantly more often than chance. The foreshortening hypothesis also predicts that in Experiments 3–5, objects along the vertical aligned axes may have appeared closer than objects along any other axes. However, further analyses showed no significant bias for vertical aligned objects. In sum, the foreshortening hypothesis fails to systematically account for our data.

[3] Note that the objects were named for participants at the beginning of the experiment in an order consistent with their viewing perspective, following Mou and McNamara (2002); however, for both 0° and 315°, the preference was to adopt intrinsic axes consistent with the display, table orientation and the structure of the room, rather than viewing perspective. Thus, the order of naming did not drive this effect.

when it was red vs. when it was black, collapsing over the location of the binder within the display. There was no significant preference for selecting the red binder ($M = .20$) over the black binder ($M = .19$) across all located object locations, $p = .77$. This means that reference object selection was based on spatial features, with no influence of perceptual features, consistent with Miller et al. (2011). With respect to object identity, we computed how often each object was selected, regardless of its location or perceptual salience. The only significant result was a bias against selecting the day planner as reference object, which was chosen significantly less often ($M = .10$) than on average ($M = .14$), $p < .048$. This is an interesting result that could be related to the fact that the dayplanner had poor name agreement. Despite the fact that we named all the objects for participants at the start of the study, some subjects who selected this object called it a calendar. It is likely that other participants were unsure of what to call it, and therefore avoided selecting it as a reference object. This would suggest that nameability might play a significant role in reference object selection, a question that we are currently addressing. Finally, with respect to object location, we computed how often an object in a given location within the display was selected. The central location was strongly preferred, with objects here selected significantly more often ($M = .32$) than on average ($M = .14$), $p < .01$. This result could be due to the fact that the central location was most often one of the closest objects.

Experiment 2

In Experiment 1, participants selected a reference object using a sentence frame that included the spatial term ‘‘by’’. This term was selected because it does not constrain interpretation to any particular location around the located object (Logan & Sadler, 1996; Miller et al., 2011), as is the case for other spatial terms. For example, using the term ‘‘left’’ would have required selection of a reference object on a particular side of the located object, and the term ‘‘next to’’ seems to carry an interpretation that is more horizontal than vertical (Logan & Sadler, 1996). For example, using the frame ‘‘The binder is next to the ____’’ could result in a biased selection of the dayplanner or notebook in Fig. 1, Panel A over the tape recorder, computer or clipboard. Nevertheless, to ensure that the findings of Experiment 1 were not due to the use of the spatial term ‘‘by,’’ we replicated the results using the following modification of Experiment 1’s procedure. Participants were told that the experimenter would provide the name of a located object, and their task was to think about how they would describe its spatial location with respect to one of the other objects in the display, and then simply point to that object. Thus, participants were still selecting a reference object, but without an explicit spatial relation. We expected to observe the same bias for selecting reference objects consistent with the assumed spatial reference direction as in Experiment 1. Because of the null effects of object orientation and viewing perspective in Experiment 1, all participants stood at 0°, and the viewed objects were oriented as in Fig. 1, Panel A. We included the perceptual salience manipulation, with some participants receiving displays with a uniquely colored binder and others receiving displays with uniformly colored (all black) objects.

Method

Participants

Seventy undergraduates from the University of Notre Dame participated in exchange for partial course credit.

Materials

The layout from Experiment 1 was used, with all seven objects oriented 0° (see Fig. 1, Panel A).

Procedure

The procedure was as in Experiment 1, except that participants were asked to think about the located object’s position with respect to one of the other objects, and to point to the reference object after the experimenter provided the name of the located object. All participants stood facing at the display at the 0° perspective. Half of the participants received uniformly colored displays and half received displays with the binder uniquely colored (red among black objects).

Results and discussion

Each reference object that was selected in the reference object selection task was coded as in Experiment 1 into the aligned axes (0–180° and 90–270°), misaligned axes (45–225° and 130–315°) and other categories (27–207°, 63–252°, 153–333°, 117–297°). Observed, a priori and expected frequencies for each category are shown in Table 1. The pattern of data shows a larger observed frequency than expected frequency for the aligned axes category and smaller observed frequencies than expected frequencies for the misaligned and other categories. A binomial test conducted on the aligned axes category revealed that the difference between observed and expected was significant ($p < .01$). Moreover, consistent with Experiment 1, chi square analyses showed no effect of object salience (uniform vs. unique) across the three categories of axes, $\chi^2(2) = 1.25$, $p = .46$. Finally, using binomial tests on the proportions, with respect to perceptual features, there was no significant preference for the red binder ($M = .18$) over black binder ($M = .15$) across all located object locations, $p = .46$. With respect to object identity, the day planner was selected as the reference object ($M = .11$) marginally significantly less often than on average ($M = .14$), $p = .08$. Finally, with respect to object location, objects at the central location ($M = .29$) were selected significantly more often than on average ($M = .14$), $p < .01$. In addition, the top location was also selected ($M = .27$) significantly more often than on average ($M = .14$, $SE = .1$), $p < .01$.

Together the results of Experiments 1 and 2 show that when selecting a reference object from a perceptually available display, participants preferred objects that were aligned along the intrinsic axes of the display. In the Experiments 3 and 4, we assess what happens when people describe the locations of objects from memory, asking whether reference object selection from memory will be influenced by the intrinsic axes that are used to initially encode the displays.

Experiment 3

In Experiment 3, participants performed three tasks: they learned the displays from a given perspective, they performed a judgment of relative direction (JRD) task that enabled us to identify the intrinsic axes that were used to organize the displays during learning, and they performed a reference object selection task under conditions in which they had to retrieve the displays from memory. We hypothesized that the objects that fell along the intrinsic axes that were used during learning would be more likely to be selected as reference objects in the spatial task.

Three additional methodological changes were made to ensure that the correspondence observed in Experiments 1 and 2 was not specific to the particular geometric structure of the displays used in those experiments. First, we used a layout in which the distances from each object to its closest objects were controlled. This was done to ensure that any observed effects were due to the intrinsic axes and not due to proximity. In Experiments 1 and 2, these were potentially confounded because the objects along the intrinsic reference axes were closer to the located object than the objects along the misaligned axes. Second, the display of objects was arranged on a round virtual table[4] (see Fig. 2, Panel A), with one direction arbitrarily labeled as 0° and all other directions labeled counterclockwise from the learning direction. This was done to remove any potential influence of the table structure on defining the intrinsic axes. Third, participants were simply asked to learn the objects and their locations. By using a round table and not providing explicit instructions, we expected that the intrinsic axes would be determined by participants' study viewpoint along the 0–180° axis (Greenauer & Waller, 2008; Li et al., 2009; Shelton & McNamara, 2001). This would enable us to generalize the results from Experiments 1 and 2 as being due to the organization of the intrinsic axes, rather than due to a particular type of information used to set up the axes, such as the layout of the objects and environmental cues, as in Experiments 1 and 2. The critical question was whether there would be a bias to select the objects along these intrinsic axes as reference objects in the spatial description task.

Method

Participants

Sixteen college students (8 women and 8 men) from Beijing Forest University participated in return for monetary compensation. The experiment was conducted in Chinese.[5]

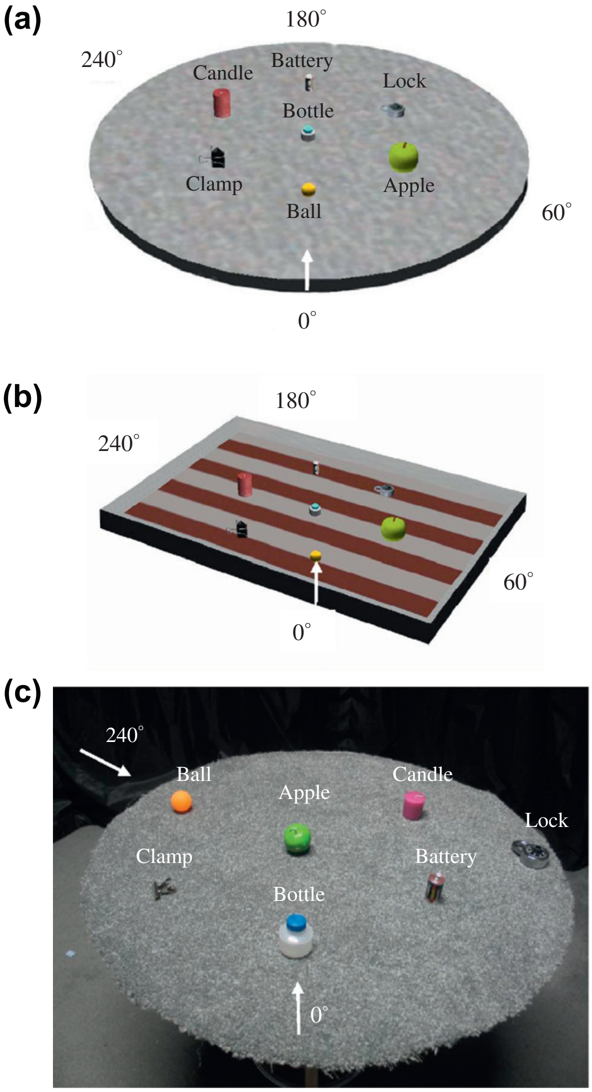

Fig. 2. Panels A–C show the learning layouts for Experiments 3, 4, and 5, respectively.

Material and design

The virtual environment included a table with a display of seven objects, and was presented in stereo with an I-glasses PC/SVGA Pro 3D head-mounted display system (HMD, I-O Display Systems, Inc. California). Participants' head motion was tracked with an InterSense IS-900 motion tracking system (InterSense, Inc., Massachusetts). The apparatus was placed in a 6 m × 6 m laboratory with each wall covered by homogeneous black curtains. As illustrated in Fig. 2, Panel A, a round virtual table (80 cm in diameter) was presented on the floor in the middle of the room. During learning, participants stood 1.9 m away from the center of the table. Across participants four different learning displays were used, with different arrangements of objects within the displays to rule out any preferences for particular objects or locations. For each of the four learning displays, there was one central object and six additional

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[4] We switched from using physical displays for Experiments 1 and 2 to virtual ones for Experiments 3 and 4 for their convenience in constructing and manipulating spatial environments (e.g., the features of the rectangular table in Experiment 4). Previous research has also observed effects of intrinsic axes on the encoding of locations using virtual displays (e.g., Mou et al., 2008; Xiao, Mou & McNamara, 2009 and Li et al., 2009).

[5] Previous studies (e.g., Greenauer & Waller, 2010; Mou & McNamara, 2002; Mou et al., 2009), have observed comparable effects of intrinsic axes on the encoding of locations across these languages and subject pools.

objects that occupied the six vertices of a regular hexagon; this configuration was used to equate proximity.

For the JRD task, each test trial was constructed using the names of three objects in the display. The task required participants to imagine standing at one object, facing a second object, and pointing to the third object (e.g., ‘‘Imagine you are at the lock, facing the battery, point to the apple.’’). There were four imagined headings: 0°, 60°, 180°, and 240°, with 0° and 180° aligned with the assumed learning direction, and 60° and 240° misaligned with the assumed learning direction. Twenty-four trials were created (six for each heading), and across headings the pointing directions were to the front, back and the sides, with an equal distribution per heading. Participants were exposed to the same number of aligned and misaligned imagined headings. Participants performed five blocks, each with 24 trials, with the order of trials randomized within a block.

For the reference object selection task, participants performed the task in a different room so that they could not view the display. They were given a sheet of paper containing the seven sentence frames (The <located object> is by (?) the _____) and asked to fill in the blank with an object from the display; the order of objects serving as the located object was randomly determined.

The order in which participants performed the judgment of relative direction task and reference object selection task was counterbalanced across participants.

Procedure

Learning phase

Four participants (2 men and 2 women) were assigned to each of the four learning displays. Before entering the learning room, each participant was trained on how to use a joystick to make the judgment of relative direction, and was familiarized with the experimental procedure and requirements. The participant was then blindfolded and led to the learning position and oriented in a given facing direction in the learning room; this facing direction varied across participants, but was labeled as 0° for all participants because it represented the viewing perspective. The lights in the room were turned off, and each participant took off the blindfold and put on the head-mounted display. The learning layout was presented for 30 s. Participants were required to learn the locations of the seven objects, and to name and to point to each object with their fingers while their eyes were closed. Participants performed five of these learning-pointing sessions. After that, the head-mounted display was removed, and participants were blindfolded and led to the testing room.

Testing phase

Participants were randomly assigned to complete either the JRD task first or the reference object selection task first, with the constraint that each group contained an equal number of men and women. For the JRD task, the participant put on an earphone and held a joystick at their waist. The test trials were presented via the earphone connected to a computer. Pointing accuracy was emphasized and speedy responses were discouraged with the instruction to ‘‘Please point only after you make sure you can point as accurately as possible’’). For the reference object selection task, participants were given the sentence frame ‘‘The <located object> is ‘‘by’’ (??) _____.’’ and were asked to fill in the blank with one of the objects from the display. Each participant performed seven trials, with each trial using one of the seven objects from the display as the located object. Each participant received the trials in a different random order.

Results and discussion

JRD task

The 0° and 180° imagined headings were combined because both were aligned with the learning direction (aligned axes); the 60°and 240° imagined headings were combined because both were misaligned with the learning direction (misaligned axes). Mean pointing latencies and pointing errors for aligned and misaligned axes are presented in Table 2. Participants were faster at pointing to objects on the aligned (0° and 180°) than on the misaligned axes (60°and 240°), with an effect size of 0.25 (Cohen's *d*), $t\ (15) = 2.475$, $p < .05$. Similarly, performance was more accurate when pointing to objects on the aligned axes (0° and 180°) than on misaligned axes (60°and 240°), $d = 0.42$, $t\ (15) = 1.86$, $p = .08$. This pattern of results was also confirmed using a combination measure of difficulty that was

Table 2
Means and standard deviations (in parentheses) for pointing errors (in degrees) and pointing latency (in seconds) for the aligned and misaligned conditions in Experiments 3, 4, and 5.

Experiment	Pointing error (in degrees)		Pointing latency (in s)	
	Aligned	Misaligned	Aligned	Misaligned
Experiment 3	30.77 (11.00)	35.52 (11.52)	3.58 (1.52)	3.99 (1.82)
Experiment 4	33.64 (11.78)	33.68 (10.04)	3.67 (1.66)	4.63 (2.35)
Experiment 5, memory				
Learning from 0°	27.54 (8.54)	38.83 (9.00)	5.70 (2.46)	5.92 (2.86)
Learning from 240°	27.18 (3.95)	33.54 (9.20)	4.60 (1.57)	5.48 (2.60)
Mean	27.36 (6.25)	36.19 (9.10)	5.15 (2.02)	5.70 (2.73)
Experiment 5, changed perspective				
Data for 1st JRD task				
Learning from 0°	28.87 (5.03)	30.63 (5.96)	4.54 (2.91)	5.44 (3.67)
Learning from 240°	24.41 (4.73)	31.23 (8.57)	4.82 (2.24)	6.01 (2.71)
Mean	26.64 (4.88)	30.93 (7.27)	4.68 (2.58)	5.73 (6.38)
Data for 2nd JRD task				
Learning from 0°	19.17 (3.65)	31.01 (6.34)	3.20 (2.27)	3.45 (2.32)
Learning from 240°	26.30 (8.23)	30.51 (12.13)	3.38 (1.51)	3.91 (1.74)
Mean	22.74 (5.94)	30.76 (9.24)	3.29 (1.89)	3.68 (2.03)

computed based on the average z-score of the absolute error and response time (Waller, Lippa, & Richardson, 2008; Waller et al., 2002); details are provided for this measure for Experiments 3–5 in the Appendix.

Reference object selection task

Objects were categorized according to their placements along three axes: 0–180° (aligned axes), 60–240° (misaligned axes), and 120–300° (other axes). For example, in Fig. 2, Panel A, with the lock as the located object, the apple would be coded as aligned axes (0–180°), the battery would be coded as misaligned axes (60–240°) and the bottle would be coded as other axes (120–300°). Participants never selected a reference object that was farther away (for example, candle), such that that all selected objects fell into one of these three categories. The a priori frequency of the possible reference object choices was distributed evenly across three types of axes (eight in each). Observed, a priori and expected frequencies are shown in Table 1.

The pattern of data in Table 1 showed that the observed frequency was higher than the expected frequency for the aligned axes category (0–180°), and the observed frequencies were lower than the expected frequencies in the misaligned (60–240°) and other axes categories (120–300°). This pattern was verified using a binomial test showing that the difference in the aligned axis category (0–180°) was significant ($p < .01$), replicating the correspondence between encoding the display and selecting reference objects that was observed in Experiments 1 and 2 when the displays were perceptually available. Subsidiary analyses revealed no effect of task order (JRD first or reference object selection task first) across the three types of axes, $\chi^2(2) = 0.50$, $p = .22$, and no preference for selecting objects at the center location, suggesting that the preference for the central location observed in Experiments 1 and 2 was due to proximity which was uncontrolled in those displays.

In all, the results of Experiment 3 indicate a significant bias in selecting reference objects from memory that were located along the axes defined by the intrinsic axes used to encode the objects, as verified by the JRD task.

Experiment 4

In Experiment 3, reference object selection was biased by the spatial reference direction defined by the viewing perspective. In Experiment 4, we generalized this result by using displays for which the spatial reference direction would be defined by environmental features. Specifically, participants learned a hexagonal layout on a rectangular table, the orientation of which was parallel to the intrinsic axis of 60–240° (see Fig. 2, Panel B). We expected that participants would select the axis of 60–240° as the spatial reference direction, relying on the geometry of the table to set up the intrinsic axes (e.g., Li et al., 2009; Mou et al., 2008). A correspondence between the spatial reference direction used to encode the display and the reference objects selected in the spatial description task should thus be revealed as a bias to select reference objects along the 60–240° axis. This effect would further generalize the results of Experiments 1–3 as being due to the intrinsic axes regardless of the source of information used to define the spatial reference direction.

Method

Participants

Sixteen college students (8 women and 8 men) from Beijing Forest University participated in return for monetary compensation. The experiment was conducted in Chinese.

Material and design

The materials, design and procedure were identical to those of Experiment 3 except that the configuration of objects was presented on a rectangular 80 cm × 120 cm table (illustrated in Fig. 2, Panel B). The table contained the stripes that are shown in the figure, in order to emphasize the table's orientation as a source of information for defining the spatial reference direction.

Results and discussion

JRD task

Based on previous research, the table structure was expected to be selected as the source of the spatial reference direction, with intrinsic axes along 60° and 240°. Accordingly, the aligned axes were defined as 60° and 240°; the misaligned axes were defined as 0° and 180°; and the other axes were defined as 120° and 300°. Mean pointing latencies and errors as a function of alignment are shown in Table 2. Participants were faster when the imagined headings were aligned with the axis of 60–240° than when misaligned, $t(15) = 4.02$, $p < .01$, $d = 0.47$. The mean angular error between the aligned (60° and 240°) and misaligned heading (0° and 180°) across participants was marginal significant, $t(15) < 1.96$, $p = .07$, $d = 0$. This pattern also held in the difficulty measures, as shown in the Appendix.

Reference object selection task

Objects were categorized according to their placements along three axes: 60–240° (aligned axes), 0–180° (misaligned axes), and 120–300° (other axes). Observed frequencies, the priori frequencies and expected frequencies are shown in Table 1. The pattern of data in Table 1 showed that the observed frequency was higher than the expected frequency for the aligned axes (60–240°) category, and the observed frequencies were lower than the expected frequencies in the misaligned (0–180°) and other axes (120–300°) categories. This was verified by a binomial test showing a significant difference for the aligned axes category. There was no effect of task order (JRD first or reference object selection task first) across the three types of axes, $\chi^2(2) = 1.20$, $p = .45$. These results show a significant bias toward selecting reference objects that were encoded in a manner consistent with the spatial reference direction, as verified by the JRD task.

A strong test of the idea that the spatial reference direction used in memory biases the reference object that is selected is to assess whether this relationship holds at an individual participant level. For example, participants who show larger differences in the JRD task between the aligned and misaligned perspectives should be more likely to pick

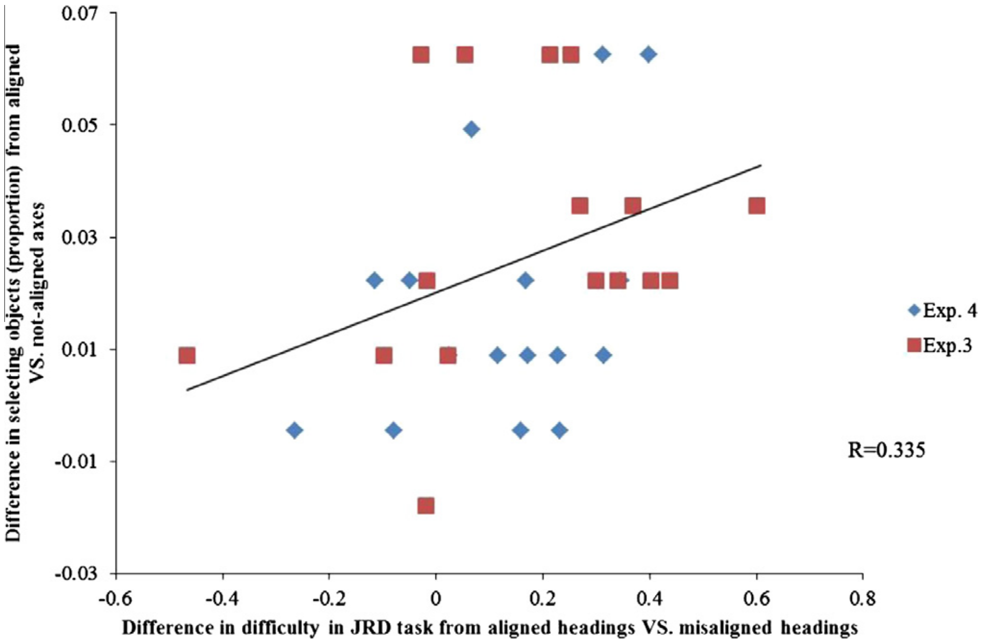

Fig. 3. The scatterplot shows the correlation between the magnitude of the difference in the difficulty measure in the JRD task between aligned imagined headings vs. misaligned headings and the magnitude of the difference in selecting objects from aligned vs. misaligned axes in the reference object selection task. Diamonds designate the data from Experiment 3; squares designate the data from Experiment 4.

reference objects along these axes in the spatial task. We assessed this by computing the correlation between the magnitude of this difference in difficulty in the JRD task and the magnitude of this difference in selecting objects from the aligned vs. not-aligned axes in the spatial description task, pooling together the data from Experiments 3 and 4. The scatter plot is shown in Fig. 3, and the correlation is marginally significant, $r\ (32) = 0.335$, $p = .06$, confirming the idea that participants who represented the objects more strongly with respect to the spatial reference direction used during learning were also more likely to choose reference objects along these axes.

Experiment 5

Experiments 1 and 2 demonstrated that selecting a reference object from a perceptually available display was biased by the spatial reference direction applied to the display during viewing. Experiments 3 and 4 demonstrated that selecting a reference object from memory was influenced by the spatial reference direction applied during learning. In Experiment 5, we set up a conflict between the perceptual display and the memory representation of the display, asking participants to learn the display from one viewpoint (which we confirmed using a JRD task), and to describe it from another viewpoint. This changed perspective condition enabled us to assess whether there would be a bias to select a reference object based on the way in which it was initially learned vs. the way in which it was currently perceived. We used the display shown in Fig. 2, Panel C for which a spatial reference direction defined by the viewing perspective was expected, as in Experiment 3. To ensure that any effects in this experiment were not tied to this change in display from Experiments 3 and 4, we also included a memory condition that replicated Experiment 3.

Method

Participants

Thirty-two (16 women, 16 men) college students from Beijing Forest University participated in return for monetary compensation. The experiment was conducted in Chinese. There were two between subject factors: initial learning viewpoint (0° vs. 240°) and testing condition (memory vs. changed perspective). These were crossed, yielding 4 conditions, with eight subjects randomly assigned into each condition.

Material and design

A cylindrical room with walls covered in black curtains was used as the learning room. As illustrated in Fig. 2 Panel C, a round table (80 cm in diameter, 70 cm in height) was placed in the middle of the room. In the layout, the distances from each object to its closest neighbors were equated. During learning, participants stood 1.2 m away from the center of the table. Four different learning scenes were used and a given object was placed in different positions across scenes to counterbalance any preferences for particular objects.

Procedure

Participants were randomly assigned to two learning perspectives (0° and 240°) and to four learning displays, such that 1 male and 1 female were assigned to each learning direction and each display. The procedures of learning and testing are the same as in Experiment 3, and included a memory condition and a changed perspective condition.

Memory condition

Participants learned the layout initially from either a 0° or 240° perspective. They then performed a JRD task, as in Experiment 3, to verify the spatial reference direction used during learning. Participants then moved to a new room from which they could not view the display, and performed the reference object selection task, following the procedure for this task from Experiment 1.

Changed perspective condition

Participants learned the layout initially from either a 0° or 240° perspective. They then performed a first JRD task, as in Experiment 3, to verify the spatial reference direction used during learning. Participants then moved to a new perspective in front of the display (those who learned at 0°, moved to 240°; those who learned at 240°, moved to 0°), and performed the reference object selection task following the procedure for this task from Experiment 1. Following this, they performed a second JRD task to assess whether their initial learned perspective was altered by the changed perspective used during the reference object selection task.

Results and discussion

JRD task

For the learning from 0° group, the imagined headings of 0° and 180° were aligned with the learning perspective, and the imagined headings of 60° and 240° were misaligned. For the learning from 240° group, the imagined headings of 60° and 240° were aligned with the learning perspective and 0° and 180° were misaligned. Within the memory and changed perspective conditions, for analysis, we combined the aligned conditions from the two learning groups, and the misaligned conditions from the two learning groups. Accordingly, the aligned conditions are defined as being consistent with learning perspective. Mean pointing latencies and pointing error broken down by learning group are shown in Table 2.

Memory condition

There was a significant effect of alignment, with participants more accurate (t (15) = 4.21, $p < .01$, $d = 1.11$) and marginally faster (t (15) = 1.85, $p = .08$, $d = 0.23$) with aligned imaginary headings than misaligned imaginary headings. This pattern also held for the difficulty measure, as presented in the Appendix. These results indicate that the intrinsic axes for the spatial reference direction were defined by the learning perspective.

Changed perspective condition

There was a significant effect of alignment, with participants both more accurate (t (15) = 4.29, $p < .01$, $d = 1.34$) and faster (t (15) = 4.97, $p < .01$, $d = 0.37$) with the aligned imaginary headings than with the misaligned imaginary headings. This pattern also held for the difficulty measure, as presented in the Appendix. These results indicate that the intrinsic axes for the spatial reference direction were defined by the learning perspective.

Participants in the changed perspective condition also performed a second JRD task after the reference object selection task. Alignment effects were also observed in these data. Specifically, participants were both more accurate (t (15) = 4.77, $p < .01$, $d = 0.96$) and faster (t (15) = 2.89, $p < .05$, $d = 0.20$) with aligned imaginary headings than with misaligned imaginary headings. For completeness, we directly compared the alignment effect across the first and second JRD tasks, using a 2 (aligned vs. misaligned) by 2 (1st vs. 2nd JRD task) mixed analysis of variance. For accuracy, there was a significant effect of alignment, F (1, 30) = 40.5, $p < .01$, $d = 1.11$, but no effects due to the JRD task ($F < 1$, and no interaction, $F < 1$. For the response time data, in addition to significant effects of alignment (F (1, 30) = 33.0, $p < .01$, $d = .28$, there was a significant main effect of JRD task, F (1, 30) = 104.6, $p < .01$, $d = .71$, with faster responses for JRD task 2 (M = 3485 ms) than for JRD task 1 (M = 5203 ms), which is most likely due to practice. In addition, there was a significant interaction between alignment and task, F (1, 30) = 6.9, $p < .01$, $d = .97$, with the size of the alignment effect smaller for JRD task 2 (M difference = 389 ms) than for JRD task 1 (M difference = 1042 ms). Note, however, that a significant alignment effect remains of the same form as observed in task 1, and the reduction may be a consequence of the speeded responding in task 2. Certainly, these analyses indicate that the spatial reference direction that was initially used in learning, as reflected in the JRD task 1 performance, remained in use for JRD task 2, despite the experience with a new perspective during the reference object selection task. This is consistent with work by Shelton and McNamara (2001) showing a preference for initial perspectives.

Reference object selection task

The objects were categorized according to their placements along three axes: 0–180°, 60–240° and 120–300°. For the learning from 0° group, 0–180° was aligned with the learning perspective, 60–240° was misaligned with the learning perspective, and 120–300° was categorized as the other axes. For the learning from 240° group, 60–240° was aligned with learning perspective, 0–180° was misaligned with learning perspective, and 120–300° was categorized as other axes. Participants never selected a reference object that was farther away; therefore, it was possible to code all responses relative to these three axes. Within the memory and changed perspective conditions, for analysis, we combined the aligned conditions from the two learning groups and the misaligned conditions from the two learning groups. There were 22 possible a priori choices (from each of the 7 objects to all the closest objects), distributed as follows across the three axes: 6 for 0–180°, 8 for 60–240° and 8 for 120–300°. Observed frequencies, a priori frequencies and expected frequencies broken down by these axis categories are shown in Table 1.

Memory condition

The pattern of data shows a larger observed frequency than expected frequency for the aligned axes category, and smaller observed frequencies than expected frequencies for the misaligned and other categories. This is confirmed by a binomial test showing a significant difference for the aligned axes category, $p < .01$. This same pattern is observed when analyzing each learning group separately, where the observed frequencies in the aligned axes category were significantly higher than the expected frequencies, $p < .05$. These results show a significant bias toward selecting reference objects that were encoded in a manner consistent with the spatial reference direction, as verified by the JRD task, and are consistent with Experiments 3 and 4.

Changed perspective condition

In contrast to the memory condition, there was no significant difference between the observed frequency and the expected frequency in the aligned axes condition, either when pooled across the learning groups ($p = .68$), or for each learning group individually (for learning from 0°group, $p = .54$; for learning from 240°, $p = .71$), indicating no strong preference for reference objects defined exclusively with respect to the initial learning perspective or the current perspective. In addition, binomial tests showed no significant preference for a given object location, as compared with the expected average proportion ($M = .14$), $p >= .79$. Moreover, all participants selected reference objects that were placed across all of the axes, with the exception of one participant who learned from 0° and always selected reference objects from 60° to 240° axes. Thus, the different data pattern observed here is not due to the selection of a particular location or the combination of different types of subjects. Instead, these results suggest that both the current viewing direction derived from the perceptual display and the reference direction established during learning were used. In this regard, it is noteworthy that the differences across the memory and changed perspective conditions seemed to be due to a change in the distribution of selection within the aligned and misaligned axes, rather than a change in selection from the other axes. Thus, these data support a link between the spatial reference direction and reference object selection, but suggest that it is not obligatory—despite preservation of the spatial reference direction that was used during initial learning (as verified in the second JRD task), participants instead sometimes used the current viewing direction that was available from the perceptually available display.

General discussion

The purpose of the current research was to assess whether the spatial reference direction used to perceive and encode a display of objects influenced the selection of a reference object from the display in a spatial description task under perceptual, memory and changed perspective conditions. Experiments 1 and 2 showed a significant influence when the display was perceptually available. These findings are consistent with the prioritization of aligned (vertically or horizontally located) reference objects when producing spatial descriptions of a currently perceived layout (Carlson & Hill, 2008; Hund & Plumert, 2007; Miller et al., 2011), and move beyond this work to offer a mechanism that provides an independent means for defining these spatial features. Experiments 3 and 4 showed a significant influence when the displays were retrieved from memory. These findings are consistent with results in the spatial memory literature about the impact of inter-object relations formed during encoding on retrieval (e.g., Mou et al., 2009; Taylor & Tversky 1992a; Taylor et al., 1999), and move beyond this work to further apply these correspondences to reference object selection within a spatial description task. Finally, in Experiment 5, the memory condition replicated Experiments 3 and 4, generalizing across changes in display configuration and modality (virtual or physical space). However, the changed perspective condition showed no preference for reference objects located on aligned or misaligned axes. Rather, the data showed that when the direction used to view the current display and the spatial reference direction used to previously learn the display were both available to participants, they both influenced reference object selection in the spatial description task. This is despite the fact that the second JRD task revealed the preservation of the initial learning perspective. What is most important about this result for current purposes is that it illustrates that the way in which the display is perceived or encoded does not obligatorily dictate the way in which it will be described. Thus, it is possible that Experiments 1–4 could have failed to find an influence of spatial reference direction on reference object selection. Indeed, the fact that in all experiments some participants chose reference objects along the other axes indicates that there is no obligation to use the spatial reference direction. Nevertheless, across Experiments 1–4 and in the memory condition of Experiment 5 there was a strong correspondence between the spatial reference direction and reference object selection, indicating a bias for the linguistic system to use the organizational scheme adopted by the perceptual and memory systems. Future research should follow up on the changed perspective condition in order to identify under such conditions of conflict, which source (perception or memory) is typically preferred. In Experiment 5 these seem to be equally weighted; however, it is possible that particular scenarios may lead to a prioritization of one spatial reference direction over another for these linguistic descriptions.

More generally, the current results point to the need to combine paradigms in spatial memory and spatial language to better assess the nature and utility of the underlying spatial representations. We did not design the current experiments to explicitly contrast the perceptual, memory and changed perspective conditions; rather, we included these conditions as a means of assessing the generalizability of this correspondence between the way in which a display is encoded and perceived and the way in which it is described. Further work is needed that directly compares these conditions to get a better sense of how such correspondence plays out at the representation level. Certainly, such a correspondence is utilitarian. We learn about objects and their locations because we often need to later find, use and describe these objects and locations. Critical to studying such correspondences will be using independent measures for each of these representations, and thereby more firmly connecting tasks and literatures across these spatial domains.

A. Appendix

To calculate difficulty, pointing latency and absolute pointing error were first each converted to *z*-scores for each trial for each participant, with the conversion based on each participant's distribution using his/her own mean score and the standard error of the two variables. The *z*-scores of two variables were then averaged on each trial to obtain a difficulty measure for that trial. The total difficulty for each participant was calculated by averaging the difficulty of all trials.

In Experiment 3, comparison of the difficulty scores averaged for aligned and misaligned axes revealed a significant alignment effect, t (15) = 2.499, $p < .05$, $d = 1.17$. In Experiment 4, there was a significant difference in the difficulty measure, with better performance for the aligned axes (60–240°) than for the misaligned axes (0–180°), t (15) = 2.739, $p < .05$, $d = 1.26$. In Experiment 5, for the memory condition, there was a significant alignment effect in the difficulty measure, with better performance for aligned imaginary headings than misaligned imaging headings, t (15) = 4.04, $p < .01$, $d = 2.00$. For the changed perspective condition, aligned conditions also showed better performance, with a significant alignment effect in the mean difficulty scores for both the first JRD task, t (15) = 4.87, $p < .01$, $d = 2.38$ and for the second JRD task, t (15) = 5.81, $p < .01$, $d = 3.00$.

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