Intrinsic array structure is neither necessary nor sufficient for nonegocentric coding of spatial layouts

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Mou and McNamara (2002) have recently theorized that nonegocentric reference frames (viz., intrinsic reference frames, based on the spatial structure of a configuration of objects) are used to organize spatial relationships in memory. The theory has not made claims about whether the intrinsic structure of a stimulus array is necessary or sufficient for such nonegocentric coding. We demonstrate that salient intrinsic axes in a layout of objects are neither necessary nor sufficient for people to use a nonegocentric reference frame in organizing spatial memory. In Experiment 1, participants were successfully instructed to adopt a nonegocentric preferred direction in memory for an array of objects with no salient intrinsic reference axes. In Experiment 2, with no instructions, participants adopted an egocentric preferred direction for an array with a salient intrinsic axis. These results suggest that physically salient array structure exerts a minimal influence in the coding of spatial memory through nonegocentric reference frames.

A central issue in the study of human learning and memory involves understanding the degree to which people use abstract, generalized mental representations of objects and events as opposed to specific concrete experiences of them. In the domain of spatial memory, this question is often addressed by examining the reference frames in which spatial relationships are encoded (e.g., Levinson, 1996; Shelton & McNamara, 2001). Relatively specific spatial memories that represent a direct record of an individual's experience may be coded by means of an *egocentric* reference frame (i.e., one defined with respect to a body part). On the other hand, relatively abstract, flexible representations may code spatial relationships that are independent of the position and orientation of the observer (i.e., nonegocentric). Such representations are commonly called *allocentric*, and are thought to organize remembered spatial information with respect to either an *environmental reference frame* (i.e., one based on a global feature, such as the North Pole) or an *intrinsic reference frame* (i.e., one defined with respect to the inherent structure of an object or configuration). Determining the circumstances under which either egocentric or allocentric reference frames are used has become a dominant theme in much of the contemporary literature on human spatial memory.

Recent work by Mou and his colleagues has suggested that, in general, intrinsic reference frames are selected during learning and are used to code interobject relations in memory. Evidence for the importance of intrinsic reference frames comes from a series of experiments by Mou and McNamara (2002) in which participants were asked

to learn the relative locations of seven objects in an array composed of orthogonal rows and columns (see Figure 1). During learning, participants viewed the array from a perspective that was misaligned with these rows by 45°. The participants subsequently made a series of judgments of relative direction from memory that asked them to imagine being at one of the objects in the array facing another object and to point to a third object (for a detailed description of the assumptions underlying judgments of relative direction, see Shelton & McNamara, 2001). These judgments were comparatively accurate for items that required participants to imagine perspectives that had been aligned with (or perpendicular to) the rows or columns of the array and were comparatively error prone for items requiring the imagination of their egocentric heading during learning. In addition to demonstrating that spatial memory is not necessarily orientation free, this finding showed that the preferred direction in spatial memory does not necessarily correspond to one's personal experience. This novel result led Mou and McNamara to conclude that, in general, intrinsic reference systems serve as the primary means of organizing spatial memory (see also McNamara, 2003; Mou, Zhao, & McNamara, 2007).

One as yet unaddressed distinction in Mou's "intrinsic theory of human spatial memory" (Mou et al., 2007) is that between *psychological intrinsic reference directions* that are used to structure a mental representation of space (e.g., Mou, McNamara, Valiquette, & Rump, 2004) and *physical intrinsic reference directions* that are physically instantiated in a given array of objects (e.g., McNamara,

Figure 1. Plan view of the stimulus array used in Experiment 2. An array of seven objects was enclosed in a cylindrical chamber. Participants viewed the array from an orientation of 315° and were given no instructions about how to learn the array.

2003; Mou & McNamara, 2002). Although much of Mou et al.'s (2004; Mou et al., 2007) theoretical framework focuses on understanding intrinsic axes as psychological constructs (e.g., in describing the reference directions that are unchanging over self-movement), these psychological axes have been routinely based on exposure to stimulus arrays that are composed of rows and columns of objects. Thus, the degree to which psychological intrinsic reference directions depend on salient physical array structure remains an open question. For example, under what conditions does salient physical array structure support the adoption of psychological intrinsic axes? More specifically, the present research aims to determine whether physical intrinsic structure is necessary or sufficient for organizing spatial memory around a nonegocentric reference direction.

This question resists resolution from the current literature, because the presence of physical intrinsic axes typically coincides with other cues during learning. For example, during their initial exposure to the array of objects, participants in the critical conditions of Mou and McNamara's (2002) experiments were instructed by the experimenter to learn the array along its columns, which composed a physical intrinsic axis that was misaligned with the participants' egocentric perspective. Mou and McNamara acknowledged that such instructions might help determine which *psychological* intrinsic axis is selected but did not consider the possibility that the instructions in their experiments were necessary for their participants to select a *physically* salient intrinsic axis as a basis for organizing memory. It is thus possible that Mou and McNamara's conclusions about the readiness of people to encode spatial information by means of a physically instan-

tiated intrinsic reference system may not apply generally but, rather, may apply only to situations in which people are instructed about how to learn their environment.

In part on the basis of Mou and McNamara's (2002) results, we conjectured that strong instructions to learn a spatial array might enable people to adopt a nonegocentric reference system, even in the absence of salient physical intrinsic axes. Thus, Experiment 1 was designed to evaluate whether salient physical intrinsic axes are necessary for people to adopt a nonegocentric reference system in memory. In general, participants' performance indicated that they were readily able to adopt a nonegocentric reference system in the absence of salient physical intrinsic axes. Having shown that salient intrinsic array structure is not necessary for the adoption of a nonegocentric reference system, in Experiment 2, we sought to determine whether such structure was sufficient to do so. Despite having learned an array with a salient intrinsic axis, in the absence of instructions, participants in Experiment 2 generally relied on egocentric experience to organize their memory of space.

EXPERIMENT 1

In Experiment 1, we examined participants' ability to represent an array of eight objects with respect to a nonegocentric reference system in the absence of salient physical intrinsic axes. Our procedure was based on that employed by Mou and McNamara (2002, Experiment 3). Like Mou and McNamara, we minimized the potential impact of an environmental reference frame by enclosing the observer and the learned array in a cylindrical room. Unlike Mou and McNamara, however, we also used a circular and symmetrical array of objects. Thus, although the array possessed a regular structure, no single axis of the array itself was inherently more salient than any other. Our instructions to participants to learn this array from a nonegocentric perspective were relatively more explicit than those reported by Mou and McNamara. Nonetheless, the experiment enabled us to assess whether a salient physical intrinsic axis within an array of objects is necessary for the acquisition of representations with a nonegocentric preferred heading.

The learning portion of the experiment is depicted in Figure 2. Participants' facing direction during learning was arbitrarily labeled 315°, and they were instructed to learn the array as if viewing it from the experimenter's viewpoint at 0°. If salient physical array structure is necessary for people to adopt a nonegocentric preferred direction in spatial memory, then, because the learned array lacks such structure, we would expect participants to perform relatively well on test items with the egocentric imagined heading of 315° and for their performance to decrease as imagined headings differ from 315°. This hypothesis is supported by a substantial body of literature in which a key role for egocentric reference frames in encoding spatial information about configurations of objects in one's environment is demonstrated (Christou & Bühlhoff, 1999; Diwadkar & McNamara, 1997; Easton & Sholl, 1995; Franklin &

Figure 2. Plan view of the stimulus array used in Experiment 1. Eight objects were equally spaced around a circular table that was centered in a cylindrical chamber. Participants viewed the array from an orientation of 315° (solid outline), but were instructed to learn the array from the experimenter's perspective at 0° (dotted outline).

Tversky, 1990; Mou & McNamara, 2002, Experiment 2; Roskos-Ewoldsen, McNamara, Shelton, & Carr, 1998; Shelton & McNamara, 1997, 2001; Sholl, 1999; Waller, Montello, Richardson, & Hegarty, 2002; Wang & Spelke, 2000). On the other hand, if a physical intrinsic axis is not necessary, the instructions to code the array nonegocentrically could enable participants to adopt a nonegocentric preferred heading. In this case, we would expect the best performance at test to be at 0°, with a steady decrease in performance as imagined headings differ from 0°.

We examined these hypothesized effects by means of planned contrasts (see Rosenthal & Rosnow, 1985) that coded the patterns of performance corresponding to preferred directions of the viewed (315°) and instructed (0°) headings (for details about the determination of contrast weights, see Levin & Neumann, 1999). For all analyses, the contrast weights that we chose accounted for the frequent observation that judgments of relative direction are typically facilitated when one is imagining headings that are exactly opposite to (i.e., counteraligned with) one's preferred reference direction (e.g., Rieser, 1989). In such situations, it can be argued that items testing counteraligned headings enable alternative strategies that improve performance (e.g., relying on the preferred orientation but reversing one's response). In our analyses, we included local minima in our contrast weights to account for this facilitation effect.

Method

Participants. Thirty-six undergraduate students (18 men and 18 women) participated in the experiment in return for course credit in their introductory psychology course.

Materials. Participants learned an array of eight common office-related objects spaced at 45° intervals around a circular table with a diameter of 1.07 m (see Figure 2). The table was located in the center of a 3.00-m-diameter enclosure constructed of black opaque fabric. Testing was conducted in another lab room down the hall from the learning room. Test questions appeared for participants in a V8 head-mounted display from Virtual Research and were composed of two stimuli: an orienting stimulus (e.g., "At the stapler facing the pencil") and a target stimulus (e.g., "Point to the tape"). Participants controlled the onset of each stimulus by pressing a handheld button, and they responded to the test questions by turning their heads to indicate the direction of the target stimulus. The participant's head direction was continually recorded by means of an inertial tracker (see Waller et al., 2002, for details of this method). Randomization and presentation of the stimuli, as well as the collection of direction estimates and latencies, were controlled through a scripting facility in the Python programming language.

Procedure. Participants were informed that they would be viewing an array of objects from one location and that the experimenter would be standing in a second location around the array. Two elements of the learning procedure were emphasized. First, participants were instructed to learn and remember where each object was, relative to all other objects in the array. Second, they were instructed to imagine and remember how the array of objects would look if they were viewing it from the location of the experimenter. Following these instructions, participants were given a practice learning session and a practice testing session (with feedback) using a separate array of four items. They were then escorted to the actual to-be-learned array, were asked to close their eyes, and were led by the experimenter into the round chamber and positioned in front of the array. The experimenter stood 45° to the right of the participant. Participants were then instructed to open their eyes and to study the array until they had adequately memorized the objects' locations.

During testing, participants were asked to make 48 judgments of relative direction. The 48 test questions were composed of six judgments at each of the eight imagined headings and were randomized separately for each participant. Absolute pointing error and latency—defined as the time from the presentation of the orienting stimulus to when the participant turned his or her head more than 10° to respond—was recorded on each trial.

Results

There was no evidence of a speed-accuracy trade-off either within or across participants. Because the effects of imagined heading on latency and error were similar, for brevity, we report only analyses on latency here. For both of the experiments that we report, the effects of imagined heading were examined by constructing 95% confidence intervals around contrast estimates representing the hypothesized effects associated with coding along either the viewed or the instructed headings (e.g., Levin & Neumann, 1999). The weights for these contrasts are presented in Table 1. Effect sizes were investigated by examining the percentage of variance that was both accounted for and unaccounted for by each contrast (for details of this approach, see Keppel & Wickens, 2004).

Mean latency at each of the imagined headings is depicted in Figure 3. The contrast representing optimal performance at the viewed heading (315°; row 2 of Table 1) fit the data moderately well (5.22 ± 1.88) and accounted for 50.73% of the variance associated with the effect of imagined heading. However, the 49.27% left unaccounted for by this contrast was more than would be expected by chance ($p < .01$), indicating a systematic effect for which the contrast could not account. Importantly, the contrast

Table 1
Custom Contrast Weights Used to Test the Hypotheses in Experiments 1 and 2

	Imagined Heading							
	180°	225°	270°	315°	0°	45°	90°	135°
0° (instructed) ^{ab}	0.25	1.25	0.25	−0.75	−1.75	−0.75	0.25	1.25
315° (viewed) ^a	1.25	0.25	−0.75	−1.75	−0.75	0.25	1.25	0.25
0° (sawtooth) ^b	−0.625	1.375	−0.625	0.375	−1.625	0.375	−0.625	1.375

Note—Row labels indicate the preferred direction of the contrast as specified by the predicted global minimum. ^aContrast used to evaluate hypothesis in Experiment 1. ^bContrast used to evaluate hypothesis in Experiment 2.

representing optimal performance at the instructed heading (0°; row 1 of Table 1) fit the data better (6.39 ± 2.46), accounting for 75.84% of the variance associated with the effect of imagined heading. Unlike the contrast for the viewed heading of 315°, the 24.16% of variance unaccounted for by this contrast was not significant ($p = .11$).

Discussion

In Experiment 1, we demonstrated that the presence of salient intrinsic axes in a stimulus configuration is not necessary for the establishment of a nonegocentric preferred direction in memory. Consistent with Mou and McNamara's (2002, Experiment 3) results, participants demonstrated a strong tendency to represent the array from a perspective that they never directly experienced during learning. Critically, however, unlike in Mou and McNamara's experiments, the array that our participants learned possessed no salient physical intrinsic axes. When subsequently asked to judge the relative directions of objects in the array, participants exhibited the best performance on items requiring them to imagine the heading that they had been instructed to learn, with pointing error and reaction times increasing as imagined headings deviated from the instructed view. Moreover, Figure 3 illustrates that relative facilitation was observed for items involving the imagined heading counteraligned with the instructed view (i.e., 180°), but not at the imagined heading counteraligned with the experienced view (i.e., 135°).

The primary reason that salient physical intrinsic structure was not necessary for participants to exhibit nonegocentric coding of the array was likely that they received instructions. To date, the role of instructions in coding spatial information has not been systematically investigated (but see Féry & Magnac, 2000, for another demonstration of their impact). However, the present finding raises the possibility that the learning instructions used by Mou and McNamara (2002)—not the physical intrinsic array structure—led to ostensibly nonegocentric coding. We examined this possibility in Experiment 2.

EXPERIMENT 2

If, as demonstrated in Experiment 1, salient physical intrinsic axes are not necessary for the adoption of a nonegocentric preferred direction of spatial memory, are they sufficient? Experiment 2 again closely replicated Mou and McNamara's (2002) Experiment 3: Participants learned the relative locations of seven objects in an array

that possessed salient physical intrinsic axes (defined by orthogonal rows and columns in the array at 0°–180° and 270°–90°), from a single perspective (at 315°) within a round enclosure (see Figure 1). However, unlike Mou and McNamara, we gave participants no instructions about how to learn the array. If the physical intrinsic structure of the array dominates coding in spatial memory, subsequent judgments of relative directions should be best on items with imagined headings that are aligned with one of the salient intrinsic axes in the array (e.g., 0° or 270°). If, however, physical intrinsic axes are not sufficient, but are used primarily in the context of other cues, such as instructions, then judgments aligned with an egocentric perspective (i.e., 315°) may be superior to those made from other imagined headings.

Method

Participants. Sixteen undergraduate students (8 men and 8 women) participated in the experiment in return for course credit in their introductory psychology course.

Materials. The stimulus items and arrangement were identical to those used by Mou and McNamara (2002, Experiment 3; see Figure 1). Participants learned the array within a circular enclosure 3.82 m in diameter, similar to that used in Experiment 1. Testing was conducted as described in Experiment 1 and used items identical to those used by Mou and McNamara.

Figure 3. Mean latency in judging relative directions in Experiment 1 as a function of imagined heading (error bars represent 95% confidence intervals that exclude between-participants variability; see Loftus & Masson, 1994). Participants viewed the array from 315°, but were instructed to learn the array from 0°.

Procedure. The procedures were generally identical to those of Experiment 1, with the exception that participants were not instructed about how to learn the array of objects.

Results

There was no evidence of a speed–accuracy trade-off, and for brevity, we report only the analyses on latency. As in Experiment 1, we created custom contrast coefficients to represent the pattern of results predicted by either egocentric or nonegocentric coding in spatial memory (see Table 1). On the basis of Mou and colleagues' (Mou & McNamara, 2002; Mou et al., 2004; Mou et al., 2007) results and conclusions, nonegocentric coding was evaluated using a sawtooth pattern that predicted optimal performance at 0°, facilitation at 90°, 180°, and 270°, and poorest performance at 45°, 135°, 225°, and 315° imagined headings. The same contrast weights used in Experiment 1, with a global minimum at 315° and facilitation at 135°, were used in this experiment in order to evaluate whether participants represented the array egocentrically from the previously viewed perspective. The contrast predicting egocentric coding of the array (315°; row 2 of Table 1) accounted for 72.36% of the variance associated with imagined heading (5.06 ± 2.89) and left a nonsignificant amount of variance unaccounted for ($p = .65$). Conversely, the contrast predicting nonegocentric coding (0°; row 3 of Table 1) fit the data poorly (-2.20 ± 4.45), accounting for only 13.03% of the variance associated with imagined headings.

Discussion

The results of Experiment 2 suggest that in the absence of additional cues, the physical intrinsic axes of a stimulus configuration have relatively little influence on people's memory of interobject spatial relations. Instead, the preferred reference direction under these conditions appears to be based on egocentric experience. These conclusions are supported by the following three observations. First, performance in Experiment 2 was best for items involving imagined headings that were aligned with the learning view and not with the salient intrinsic axes. Second, pointing errors and reaction time increased monotonically as imagined headings deviated from the participants' orientation at learning. Third, the only exception to this monotonic pattern was a relative facilitation at 135°, which was counteraligned with the learning view and not with the salient physical intrinsic axes. Thus, there was no evidence in our data of the relative facilitation at 90°, 180°, and 270° that is often regarded as evidence for the use of intrinsic axes in spatial memory.¹

GENERAL DISCUSSION

Recent theoretical work in human spatial memory has suggested that, in general, intrinsic reference frames are selected and used to code interobject spatial relationships in memory (McNamara, 2003; Mou & McNamara, 2002; Mou et al., 2007). This theory was developed in part to explain the ability of people to code spatial information by means of a nonegocentric (i.e., intrinsic) reference frame,

Figure 4. Mean latency in judging relative directions in Experiment 2 as a function of imagined heading (error bars represent 95% confidence intervals that exclude between-participants variability; see Loftus & Masson, 1994). Participants learned the array from 315°.

especially when the physical intrinsic stimulus structure is salient (Mou & McNamara, 2002). The present results have demonstrated that a salient physical intrinsic axis in a layout of objects is neither necessary (Experiment 1) nor sufficient (Experiment 2) for people to use a nonegocentric reference frame in organizing spatial memory. In particular, in Experiment 1, we showed that cues other than salient intrinsic or environmental structure (e.g., instructions) can influence people to represent spatial relationships by means of a nonegocentric reference frame. Conversely, in Experiment 2, we showed that when salient physical intrinsic structure is present, in the absence of those additional cues, people appear to represent spatial relationships by means of an egocentric reference frame (however, for different results using smaller arrays and alternative learning procedures, see Mou, Liu, & McNamara, in press). In the context of Mou et al.'s (2007) intrinsic theory, these results suggest that the influence of physical intrinsic structure on psychological intrinsic reference frames is minimal.

Two interpretations of these findings differ with respect to the emphasis placed on the use of psychological intrinsic reference frames in spatial memory. First, according to Mou et al.'s (2004; Mou et al., 2007) intrinsic theory of spatial memory, people generally store spatial relationships in memory with respect to a psychological intrinsic frame of reference. Under this conceptualization, the axes used to code spatial memory need not be based on the most perceptually salient array structure but can be based on other, less obvious array properties. The present results can be accounted for by this theory in part on the basis of Mou et al.'s (2007) supposition that “a collection of objects will have an infinite number of possible intrinsic axes” (p. 145). Intrinsic structure, instructions, and egocentric experience can all serve as cues to the selection of one of these myriad intrinsic reference directions. By this view, Experiment 1 simply illustrates the ability of

instructions to dominate egocentric experience in the selection of a psychological intrinsic axis. Likewise, Experiment 2 illustrates the ability of egocentric experience to serve as an effective cue for establishing a psychological intrinsic reference direction.

However, an alternative account of these findings could dispense with the notion that memory is necessarily coded by means of psychological intrinsic reference frames and could posit that, especially in the absence of instructions or salient environmental or physical intrinsic cues, spatial information is encoded simply by means of an egocentric reference frame. Thus, rather than holding that in our Experiment 2, one of an infinite number of intrinsic reference directions was selected on the basis of an egocentric cue, one could hold that participants encoded the array by means of an egocentric reference frame. According to this conceptualization, many of the recent findings in the literature demonstrating a role for intrinsic reference systems can be reinterpreted as evidence for the use of an egocentric reference system. For example, Mou et al.'s (2007) results showing that participants generally performed best on imagined headings aligned with an experienced view along the axis of bilateral symmetry can be interpreted as the use of a preferred egocentric experience based on a view that most efficiently organized the to-be-remembered information.

Among the cues that are available for organizing spatial memory, one influential yet relatively unexplored cue is the learner's instructional set. Additional investigation into the nature and strength of the influence of instructions can inform us about the flexibility of spatial encoding and the influence of higher level cognition on spatial representation. For example, it is worth noting that the effect of the instructions in Experiment 1 may have been enhanced by the relatively elaborate training procedures and by the presence of the experimenter during learning. In our study, the experimenter devoted quite a bit of time to instructing participants, and participants were allowed to practice (with feedback) on a sample array before learning the actual array. Moreover, the experimenter embodied the to-be-imagined viewpoint during learning. It is an empirical question whether a less intensive learning procedure would have led to more egocentric coding. On the other hand, it is also an open empirical question whether participants could have been instructed to adopt a reference frame that was even more disparate from their egocentric experience than the 45° difference used in Experiment 1.

It is important to note that these experiments do not imply that the intrinsic structure of a stimulus array is necessarily irrelevant for the selection of reference frames in spatial memory. Nor do the present results necessarily indicate that intrinsic reference frames are never used to code spatial information in memory. Instead, this work, in conjunction with prior findings in the literature, is most consistent with the idea that intrinsic stimulus structure can be prominently represented in memory, especially when it is accompanied by other cues, such as instructions, during learning (Mou & McNamara, 2002), egocentric experience (Mou et al., 2007), or global environmen-

tal structure (Shelton & McNamara, 2001). For situations in which people are not instructed how to learn (and in which salient physical intrinsic axes are not reinforced or emphasized by other cues), it is, however, a tenable hypothesis that egocentric reference frames provide a default coding scheme for spatial memory. It is thus possible that the flexibility of human spatial behavior does not always derive from abstract allocentric internal representations but, rather, may frequently be based on mental processes that are deployed on relatively specific egocentric representations.

AUTHOR NOTE

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REFERENCES

- CHRISTOU, C. G., & BÜLTHOFF, H. H. (1999). View dependence in scene recognition after active learning. *Memory & Cognition*, **27**, 996-1007.
- DIWADKAR, V. A., & MCNAMARA, T. P. (1997). Viewpoint dependence in scene recognition. *Psychological Science*, **8**, 302-307.
- EASTON, R. D., & SHOLL, M. J. (1995). Object-array structure, frames of reference, and retrieval of spatial knowledge. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **21**, 483-500.
- FÉRY, Y. A., & MAGNAC, R. (2000). Attenuation of alignment effect with exocentric encoding of location. *Perception*, **29**, 789-799.
- FRANKLIN, N., & TVERSKY, B. (1990). Searching imagined environments. *Journal of Experimental Psychology: General*, **119**, 63-76.
- KEPPEL, G., & WICKENS, T. D. (2004). *Design and analysis: A researcher's handbook* (4th ed.). Upper Saddle River, NJ: Prentice Hall.
- LEVIN, J. R., & NEUMANN, E. (1999). Testing for predicted patterns: When interest in the whole is greater than in some of its parts. *Psychological Methods*, **4**, 44-57.
- LEVINSON, S. C. (1996). Frames of reference and Molyneux's question: Crosslinguistic evidence. In P. Bloom, M. A. Peterson, L. Nadel, & M. F. Garrett (Eds.), *Language and space* (pp. 109-169). Cambridge, MA: MIT Press.
- LOFTUS, G. R., & MASSON, M. E. J. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin & Review*, **1**, 476-490.
- MCNAMARA, T. P. (2003). How are the locations of objects in the environment represented in memory? In C. Fleska, W. Brauer, C. Habel, & K. Wender (Eds.), *Spatial cognition III: Routes and navigation, human memory and learning, spatial representation and spatial reasoning* (pp. 174-191). Berlin: Springer.
- MOU, W., LIU, X., & MCNAMARA, T. P. (in press). Layout geometry in encoding and retrieval of spatial memory. *Journal of Experimental Psychology: Human Perception & Performance*.
- MOU, W., & MCNAMARA, T. P. (2002). Intrinsic frames of reference in spatial memory. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **28**, 162-170.
- MOU, W., MCNAMARA, T. P., VALIQUETTE, C. M., & RUMP, B. (2004). Allocentric and egocentric updating of spatial memories. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **30**, 142-157.
- MOU, W., ZHAO, M., & MCNAMARA, T. P. (2007). Layout geometry in the selection of intrinsic frames of reference from multiple viewpoints. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **33**, 145-154.
- RIESER, J. J. (1989). Access to knowledge of spatial structure at novel points of observation. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **15**, 1157-1165.
- ROSENTHAL, R., & ROSNOW, R. L. (1985). *Contrast analysis: Focused comparisons in the analysis of variance*. Cambridge: Cambridge University Press.

- ROSKOS-EWOLDSSEN, B., McNAMARA, T. P., SHELTON, A. L., & CARR, W. (1998). Mental representations of large and small spatial layouts are orientation dependent. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **24**, 215-226.
- SHELTON, A. L., & McNAMARA, T. P. (1997). Multiple views of spatial memory. *Psychonomic Bulletin & Review*, **4**, 102-106.
- SHELTON, A. L., & McNAMARA, T. P. (2001). Systems of spatial reference in human memory. *Cognitive Psychology*, **43**, 274-310.
- SHOLL, M. J. (1999). Egocentric frames of reference used for the retrieval of survey knowledge learned by map and navigation. *Spatial Cognition & Computation*, **14**, 475-494.
- WALLER, D., MONTELLO, D. R., RICHARDSON, A. E., & HEGARTY, M. (2002). Orientation specificity and spatial updating of memories for layouts. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **28**, 1051-1063.
- WANG, R. F., & SPELKE, E. S. (2000). Updating egocentric representations in human navigation. *Cognition*, **77**, 215-250.

NOTE

1. Note that Mou and McNamara's (2002) general pattern of results—relative facilitation for imagined headings aligned with the physical intrinsic structure—has been replicated in our lab using the stimuli described in Experiment 2 with the learning procedure (i.e., with instructions) they employed. Thus, the findings from the present experiment do not represent a general failure to replicate Mou and McNamara's results. Rather, they suggest a specific and strong effect of instructions in their experiments.

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