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Social and Representational Cues Jointly Influence Spatial Perspective-Taking

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Abstract

We examined how social cues (the conversational partner's viewpoint) and representational ones (the intrinsic structure of a spatial layout) jointly shape people's spatial memory representations and their subsequent descriptions. In 24 pairs, Directors studied an array with a symmetrical structure while either knowing their Matcher's subsequent viewpoint or not. During the subsequent description of the array, the array's intrinsic structure was aligned with the Director, the Matcher, or neither partner. According to memory tests preceding descriptions, Directors who had studied the array while aligned with its structure were more likely to use its orientation as an organizing direction. Directors who had studied the array while misaligned with its structure used its orientation more frequently as an organizing orientation when knowing that the Matcher would be aligned with it, but used their own viewpoint more frequently as an organizing direction when not knowing the Matcher's viewpoint. Directors also adapted their descriptions strategically, using more egocentric expressions when aligned with the intrinsic structure and more partner-centered expressions when their Matchers were the ones aligned with the structure, even when this information wasn't available in advance. These findings suggest that speakers are guided by converging social and representational cues to adapt flexibly the organization of their memories and the perspectives of their descriptions.

Keywords: Perspective-taking; Spatial memory; Intrinsic structure; Audience design; Common ground; Spatial descriptions

1. Introduction

People routinely have to access spatial information from memory and convey it to their conversational partners in order to coordinate in a range of activities, from arranging a

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meeting point on campus to describing the layout of a recently visited museum. When people coordinate in such real-world circumstances, they often occupy different vantage points, as for example when they move a piece of furniture together or when one provides directions to the other over the phone. Moreover, the real-world environments that people describe or within which they coordinate are often systematically organized, having axes of symmetry or salient landmarks. When selecting the perspective from which to describe a spatial arrangement, people therefore consider not only their partner's vantage point but also other representational cues, intrinsic to the arrangement. In the present work, we investigate precisely how people weigh these social and representational cues when spontaneously organizing spatial information in memory and when subsequently describing it.

When people make spatial judgments, they access memory representations that maintain spatial relations around a preferred organizing direction (e.g., McNamara, 2003; Mou, McNamara, Valiquette, & Rump, 2004). The selection of a preferred direction involves interpreting a spatial configuration in terms of a reference system (a process analogous to determining its "top"). A consequence of this organization is that spatial relations specified with respect to the preferred direction can be retrieved from memory more readily than those relations that are not explicitly specified and thus have to be inferred. The preferred direction of spatial memories is often determined by egocentric preferences for organizing information based on one's initially experienced viewpoint (Richard & Waller, 2013; Shelton & McNamara, 2001). But it can also be influenced by representational cues, such as the environment's geometry (Shelton & McNamara, 2001), the intrinsic features of the spatial configuration arising from its symmetry (Li, Carlson, Mou, Williams, & Miller, 2011; Mou & McNamara, 2002) and orthogonality (Richard & Waller, 2013), functional features of landmarks in the configuration (Taylor & Tversky, 1992), and even explicit instructions (Greenauer & Waller, 2008). When organizing spatial information in memory, people also seem to take social cues into consideration, such as their conversational partner's viewpoint (Galati, Michael, Mello, Greenauer, & Avraamides, 2013; Shelton & McNamara, 2004). However, the extent to which they do so is still unclear.

One study by Shelton and McNamara (2004) examined whether describing spatial information from the partner's viewpoint influences speakers' resulting memory representations. After describing a randomly configured layout to their partner who could not freely interact with them, speakers indeed used their partner's viewpoint as an organizing direction. They were more accurate to make spatial judgments from perspectives aligned with the one that had been occupied by their partner than from other perspectives (including their own). However, because in this study, speakers were explicitly instructed to use their partner's viewpoint for the descriptions (during which they built their memory representations), it is not surprising that they used their partner's viewpoint as an organizing direction.

The question therefore remained as to whether in fact speakers *spontaneously* organize their memory representations around their partner's viewpoint. We recently adapted Shelton and McNamara's (2004) study to examine this. In Galati et al. (2013), one participant first studied a randomly configured layout, while either knowing or not knowing their partner's subsequent viewpoint, which was misaligned by 90°, 135°, or 180°. In memory tests *preceding* descriptions, we found no facilitation for the partner's viewpoint when it was available (cf. Shelton & McNamara, 2004). Nevertheless, despite not using their partners' viewpoint as an organizing direction, speakers did represent that viewpoint in memory: They took longer to imagine orienting to perspectives known to be aligned with their partner (at least when partners where misaligned by 90° and 135°) and rotated their array drawings by a few degrees toward the partner's viewpoint. These findings suggest that when speakers are not "forced" to adopt a particular viewpoint and can interact freely with their partners, they may not have sufficient pragmatic motivation to invest the cognitive effort at study to organize spatial relations around a nonegocentric viewpoint. Instead, they represent the partner's viewpoint and use it later as needed.

In the present study, we ask whether reinforcing the partner's viewpoint with additional cues, such as the orientation of the intrinsic structure of the layout, *could* afford sufficient pragmatic motivation to organize spatial relations around the partner's viewpoint. Our view is that, when selecting a direction for organizing spatial relations in memory, people consider a confluence of different sources of information, including egocentric cues (e.g., their own learning viewpoint), representational cues (e.g., the orientation of the layout's intrinsic structure), and social cues (e.g., the partner's viewpoint), combining them probabilistically according to their salience and relevance to the task. This is broadly compatible with the proposal that the selection of the organizing direction from which to learn and remember a spatial layout depends on a number of cues, including spatial and nonspatial properties of the objects, the structure of the surrounding environment, the observer's egocentric viewpoint, and verbal instructions (Mou & McNamara, 2002; Shelton & McNamara, 2001). We agree, but we do not ascribe precedence to egocentric experience (Richard & Waller, 2013; Shelton & McNamara, 2001) or to the intrinsic structure of the layout (Mou & McNamara, 2002) as the dominant cue; instead, our approach emphasizes the probabilistic combination of all available cues. Thus, we expect that in a collaborative task the relation of the orientation of the configuration's intrinsic structure to one's own viewpoint and to their conversational partner's viewpoint should determine the direction selected to organize spatial relations in memory: when either person's viewpoint is reinforced by the intrinsic structure's orientation, it should be more likely to be used as an organizing direction.

This prediction is also consistent with the proposal that, in collaborative tasks, people share responsibility for mutual understanding and try to minimize their collective effort, with one partner investing greater cognitive effort to ensure mutual understanding upon appraising that the other is likely to find the interaction difficult (Clark, 1996; Clark & Wilkes-Gibbs, 1986). To determine who might find the task most difficult, people consider different sources of information, including what has been shared through spoken utterances (their linguistic co-presence) and what is visually available in their shared environment (their physical co-presence) (Clark & Brennan, 1991; Clark & Marshall, 1981).

A growing body of evidence suggests that such social cues modulate people's attributions about the partner's ability to contribute to the task at hand, and thus influence whether they adopt their partner's spatial perspective. Specifically, people are more likely to invest the cognitive effort to adopt their partner's perspective when they perceive the partner to be limited in some way. For instance, when listeners believe that their partners do not know their viewpoint they are more likely to interpret spatial descriptions from the partner's perspective, whereas when they believe that their partner is real (vs. simulated) they are more likely to interpret descriptions egocentrically, presumably because they shift the burden of ensuring mutual understanding to the partner (Duran, Dale, & Kreuz, 2011). Similarly, in production tasks, when speakers describe simple or randomly configured layouts, they are more likely to use their partner's perspective when the partner does not share their viewpoint (Mainwaring, Tversky, Ohgishi, & Schiano, 2003; Schober, 1993, 1995), is imaginary (Schober, 1993), cannot provide feedback (Shelton & McNamara, 2004), or has worse spatial abilities than they do (Schober, 2009). And when describing routes in a familiar urban environment to an imaginary partner unfamiliar with the environment (vs. for themselves), speakers elaborate their descriptions by using more words and details and referring to more landmarks for orienting, while also simplifying the routes by navigating along fewer, larger and more prominent streets (Hölscher, Tenbrink, & Wiener, 2011). This last study underscores that social cues (e.g., the partner's familiarity with the environment) guide the extent to which representational cues (e.g., landmarks and other salient features of the environment) are utilized in descriptions, in line with our proposal that multiple sources of information interact during spatial reasoning.

However, our earlier work has examined whether a single social cue (the availability of the partner's viewpoint) influences perspective selection (Galati et al., 2013). The present work examines how social *and* representational cues may jointly influence the preferred direction of people's memory representations and the perspective of their descriptions. In addressing this question, we also aim to clarify the extent to which people rely on the organization of their memory representations to describe spatial information when representational and social cues become available at different time points. For instance, when speakers discover their partner's viewpoint relative to a symmetrical configuration only after they have already encoded the configuration in memory, do they select the perspective of their descriptions according to the organization of their memories or according to the new, perceptually available information? Most earlier studies do not speak to this issue as they focus on speakers' perspective choices when they describe spatial information that is visually accessible (e.g., Schober, 1993, 1995; 2009; Mainwaring et al., 2003), where the learning of spatial information co-occurs with the description (Shelton & McNamara, 2004), or where their underlying memory representations of familiar environments are not directly assessed (Hölscher et al., 2011).

In our earlier work, in which we dissociated the learning of spatial layouts from their description and examined speakers' memory representations directly, we found that speakers don't merely rely on their initial representations but are able to use perceptually available information (i.e., their degree of misalignment from their partners) to adapt descriptions appropriately (Galati et al., 2013). When perspective-taking was relatively easy for speakers during the description (when misaligned by the small offset of 90° from their partners) speakers used partner-centered expressions more often, whereas when perspective-taking was relatively difficult (when misaligned by the oblique offset of 135°) they used egocentric expressions more often. Advance knowledge of the partner's viewpoint did not determine on its own the perspective of speakers' descriptions, although it did enable partners to recognize in advance when perspective-taking would be most difficult for each of them and to adapt their strategies in ways that facilitated coordination.

Here, we examine whether speakers will adapt just as flexibly when the configuration has an intrinsic structure. After studying such a configuration, speakers have to describe it to a partner who tries to reconstruct it from a different spatial viewpoint, such that its intrinsic structure is aligned with the speaker, their partner, or neither partner. We expect that speakers will adapt their descriptions by combining all cues, whether available in advance or at the interaction, with the aim of minimizing the collective effort of themselves and their partner (e.g., Clark, 1996; Clark & Wilkes-Gibbs, 1986). This prediction —that the "optimal" perspective will be the one reinforced by multiple cues—contrasts with the proposal that speakers initially behave egocentrically and consider their partner's perspective only later, in order to repair misunderstandings (Horton & Keysar, 1996; Keysar, Barr, Balin, & Paek, 1998; Keysar, Barr, & Horton, 1998). Such a "two-stage" model of adaptation in perspective-taking would predict that speakers should opt for their own viewpoint as the organizing direction of their memories and, at least initially, describe that information to their partner from their own perspective.

Instead, we predict that if the convergence of available cues at the description strongly biases a particular perspective (e.g., when the partner's viewpoint and the structure's intrinsic orientation coincide), speakers can override their initial memory representation (even an egocentric one) when selecting the perspective of their descriptions. Advance knowledge of the partner's viewpoint and its relation to the intrinsic structure may still influence descriptions if it highlights alternative perspectives for encoding and describing the layout that would facilitate coordination during the description. For instance, knowing the partner's viewpoint while studying the layout from an oblique viewpoint may make the structure's axis of symmetry more apparent and influence both how speakers organize spatial information in memory and how they describe it. To our knowledge, this study is the first to systematically examine how multiple cues interact as they become available during the course of spatial-perspective taking.

2. Method

2.1. Design

Directors first studied a layout that had an intrinsic structure, then their memory of the layout was assessed, and finally they described the layout to a partner—their Matcher—who reconstructed the layout on the basis of the Directors' descriptions. Between pairs, we manipulated the alignment of the layout's intrinsic structure with either partner during the description: Some Directors studied layouts while aligned with the orientation of the intrinsic structure (referred to as 0°, see Fig. 1) and later described it to a Matcher who was offset by 135°, measured counterclockwise from 0° (*Aligned with Director* condition). Others studied layouts from 225° and later described it to a Matcher who was at 0° (*Aligned with Matcher* condition). And yet others studied layouts again from 225° and later described to a Matcher who was offset by 135°; as such, both partners were misaligned with the orientation of the intrinsic structure (*Aligned with Neither* condition). We also manipulated the partners' advance knowledge of their respective viewpoints during the description: Half of the Directors in each alignment condition studied the layout while knowing where their Matcher would later be, whereas the remaining did not.[1] Thus, the partners' alignment with the intrinsic structure's orientation and the Directors' advance knowledge of their partner's viewpoint were both between-subjects factors.

2.2. Participants

Forty-eight undergraduate and graduate students (24 pairs) from the University of Cyprus participated for payment or as unpaid volunteers. Half of the participants participated as Directors and the remaining half as Matchers. Of the 24 Director–Matcher pairs, 6 were female-female pairs, 6 were male-male pairs, 6 were mixed-gender pairs with female Directors, and 6 were mixed-gendered pairs with male Directors.[2] All pairs of participants were recruited to be friends.

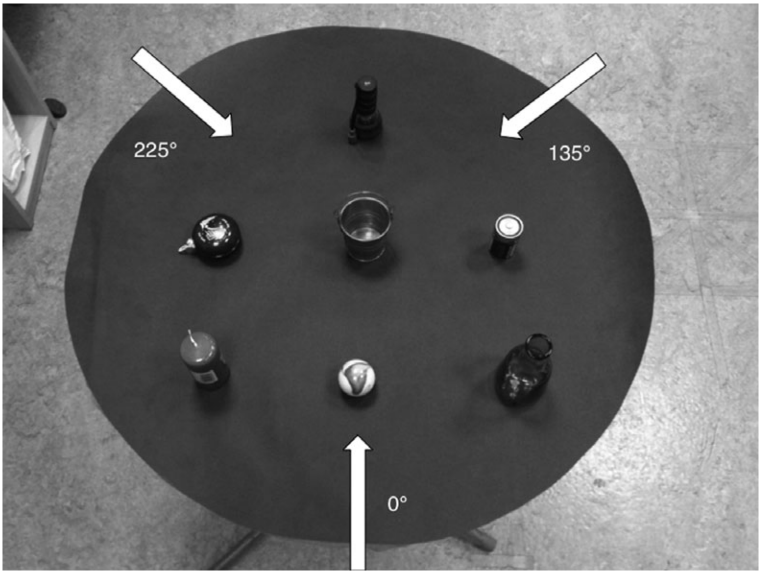

Fig. 1. The seven-object array used (including a flashlight, yoyo, bucket, battery, candle, marble, and vase), indicating 0°, 135°, and 225° headings.

2.3. Procedure

Upon the pair's arrival to the lab, it was explained that one of them, serving as the coordinator (Director), would study an array of real objects, have their memory of it tested, and then describe it to the other participant, serving as the collaborator (Matcher), who would reconstruct it at their own table based on the Director's description. Participants then gave informed consent for participation; they could also sign an optional release form for use of their video and audio data for scientific purposes.

2.3.1. Practice phase

Directors then completed a practice phase to familiarize them with the *Judgments of Relative Direction* (JRD) task, while Matchers waited in the testing room. While seated at 180° (relative to the intrinsic structure of the test array), they studied an array of four objects (a right-angle trapezoid) without a time limit to memorize it. They then practiced performing JRDs, first through pointing with the hand and with visual access to the array, and then through pointing with a joystick for trials presented on a computer and without visual access to the array. On each JRD trial, Directors were instructed to imagine being at one location (station object) facing a second (orienting object), constituting an imagined heading or viewpoint, and to point to a third object, the target (e.g., *Imagine being at x, facing y. Point to z.*).

2.3.2. Study phase

After the practice phase, Directors studied the test array, while either aligned or misaligned with its structure (from either 0° or 225°) and while either knowing where their Matcher would be during the description phase or not.

The test array was a configuration that had an axis of symmetry and comprised seven common objects, which lacked intrinsic front-back and left-right axes. As Fig. 1 shows, the configuration was symmetrical around a central axis (formed by the marble, bucket, and flashlight). It was displayed on a 70 cm-diameter circular table, and all the distances between adjacent objects along the structure's axes were 17.5 cm.

When the Matcher's viewpoint was known at study, the Matcher sat at a separate, identical table next to the Director's (see Fig. 2) at the position they would occupy during the description (at 0° or at 135°); both partners were explicitly told that this would be the Matcher's subsequent position. When the Matcher's viewpoint was not known at study, the Matcher waited in the adjacent testing room. Once the Directors indicated they had learned the array, they were verbally administered six JRD trials while wearing a blindfold that prevented visual access to the objects. At this stage, Directors could remove the blindfold to study the array further if needed.

2.3.3. Testing phase

Directors then moved to an adjacent room to complete the two memory tasks. Testing was not in the study room in order to ensure that Directors used an enduring off-line spa-

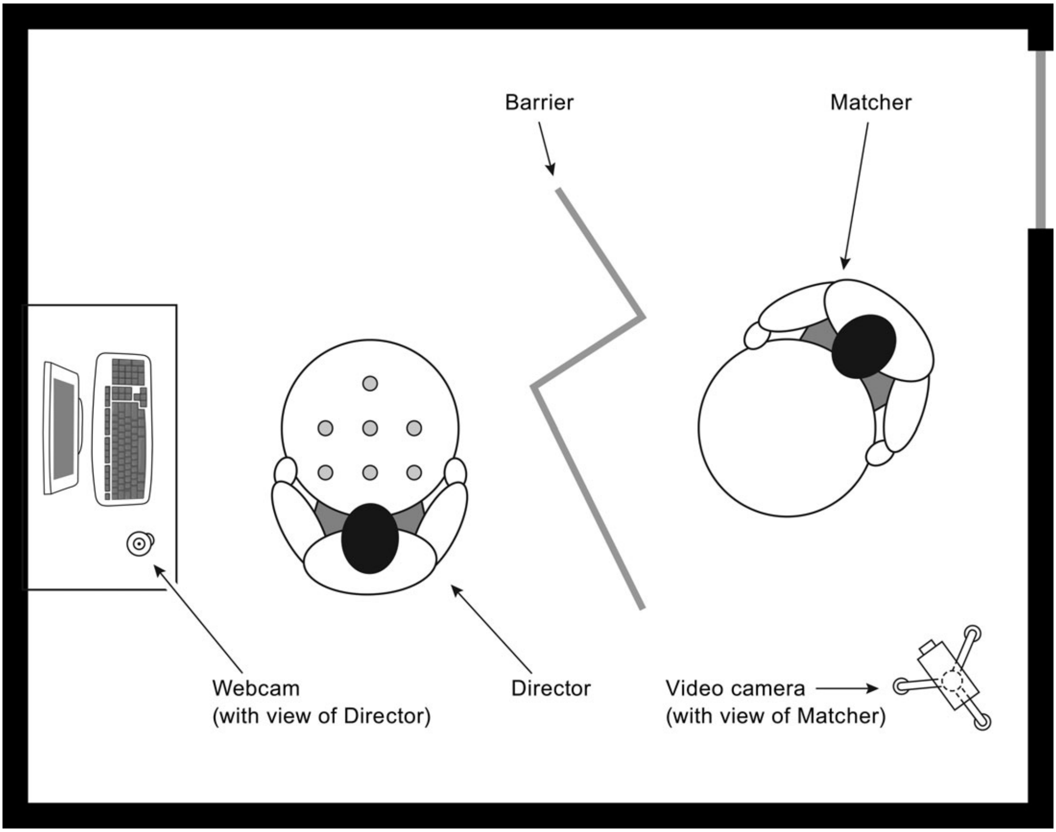

Fig. 2. Setup of a study phase in which the Director was aligned with the array's intrinsic structure (at 0°), while the Matcher was misaligned with it (at 135°).

tial representation as opposed to a transient sensorimotor representation of the array (see Avraamides & Kelly, 2008, for a discussion).

2.3.3.1. Judgment of relative direction (JRDs): On a given JRD trial, Directors first read a statement in the form "*Imagine being at x, facing y,*" (e.g., "*Imagine being at the bucket, facing the marble*"), pressed a button on a joystick once they adopted that heading, and then responded to a second statement in the form "*Point to z*" (e.g., "*Point to candle*") by deflecting the joystick in the direction of z as if they were facing y and pressing a button to log in their response. Sixty-four such trials were presented individually on a computer screen at a comfortable distance from the participants. They included eight imagined headings (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315° relative to the orientation of the intrinsic structure) and their order was randomized. In selecting the trials, we aimed to represent equally each combination of station and orienting objects corresponding to each heading, balancing the number of trials with right and left responses, and representing objects comparably as station points, orienting objects and targets.

Our measures of interest were the Directors' orientation and response latencies.[3] Orientation latency was defined as the time from the offset of the instruction to adopt an imagined perspective to the press of the joystick button to indicate that the imagined perspective was adopted. Response latency was defined as the time from the offset of the instruction to point to the target object to the press of the button to log the response after deflecting the joystick.

2.3.3.2. Array drawings: After the JRDs, Directors were given a 20 cm-diameter grid (with 1 mm lines) representing the display table and were asked to reconstruct as accurately as possible the studied array by placing on the grid seven circular transparent markers, each labeled with a name of the array's objects and a dot in the center representing the object's center. For each Director, after completion, the position of the dot for each marker was noted on the grid along with the object's name, and the participant's viewing perspective during the drawing task with an arrow at the bottom (see Fig. 3).

We were primarily interested in whether the arrays were drawn from an orthogonal or oblique perspective relative to the structure (i.e., drawn aligned or misaligned with the structure).

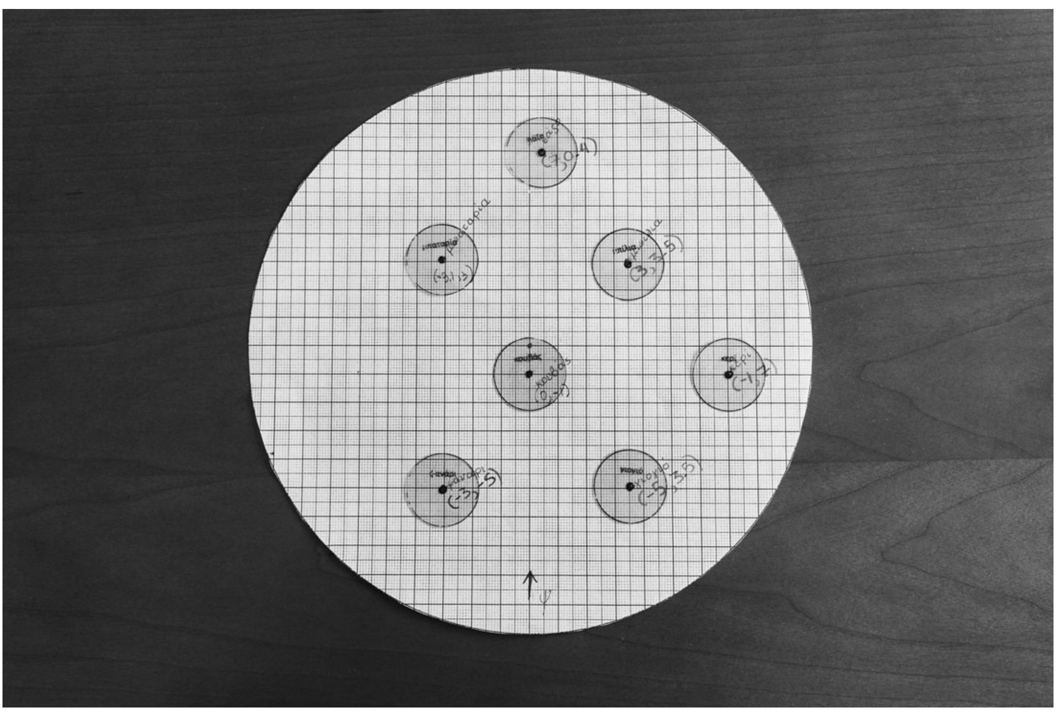

Fig. 3. Example of a Director's array drawing annotated with the coordinates of each object's location as placed by the Director on the circle, along with the Director's reconstruction viewpoint (indicated by the arrow at the bottom). This drawing was visually classified by coders as being drawn from a misaligned perspective (roughly 225°, which was indeed the Director's study viewpoint). The rotational parameter θ confirmed that this array was in fact drawn from 249°.

2.3.4. Description phase

After the testing phase, Directors returned to the original room for the description. Directors described the array's configuration from memory, while the Matcher used the seven objects to reconstruct the array at their own table. Instructions to both participants emphasized that they could interact freely and that they should reconstruct the array so that, given the Director's viewpoint at study, objects be translated to the Matcher's table (i.e., not rotated by the Matcher's offset). Directors were not restricted in how they could describe the objects to the Matchers: They were told that they were free to describe the objects from their own perspective, their Matcher's perspective, a third perspective, focus on the relationships between objects, a combination of these options, or in any other way they wished. Similarly, Matchers were not restricted in terms of the feedback they could provide. Their only restriction was that Directors could not look over the barrier (113 cm tall) that separated them to monitor how Matchers reconstructed the objects on their table. After turning on the cameras, the experimenter left the room for the description phase.

After completing the description phase, pairs were given a brief questionnaire about how well acquainted they were with each other, were debriefed, and compensated with 10 Euros for their time, if paid. Experimental sessions took about 1 h.

2.4. Coding the Directors' descriptions

2.4.1. Spatial expressions

Upon transcribing each pair's interaction during the description phase in detail, including contributions by both Directors and Matchers, we identified spatial expressions in the Directors' turns. We considered spatial expressions to include (a) locative adverbs, for example, "to your left" (*aristera su*), "in between" (*anamesa*), "next to" (*dhipla*); (b) geometric shapes and metrics, for example, "straight line" (*efthia grammi*), "triangle" (*trigono*), "ninety degrees" (*eneninta mires*); (c) directional verbs accompanied by a spatial adverb, for example, "go up" (*pienne pano*); (d) verbs describing spatial relationships or the movement of objects, for example, "it sticks out a bit" (*eksehi llio*), "increase the angles" (*megalos'tes gonies*); (e) spatial adjectives, for example, "distant" (*apomakrismeno*); and (f) abstracted shapes used as analogies for the intrinsic structure "it looks like a house" (*miazi me spiti*).

We adapted our coding scheme from Galati et al. (2013) to classify spatial expressions in the Directors' turns as being from:

1. the Director's perspective (Director-centered), for example, "in front of me is the marble" (*mprosta mu en i mpilia*)
2. the Matcher's perspective (Matcher-centered), for example, "the vase is to your left" (*to vaso en sta aristera su*)
3. a nonperson centered heading aligned with the axis of the intrinsic structure (Structure-centered). In the following example, a Director at 225° uses three spatial adjectives (*perpendicular*, *left*, and *right*) from a Structure-centered perspective with a Matcher at 135°: "On the perpendicular. You're supposed to be on one side on the

left, and I'm on the one side of the table on the right." (*sto katheto. esi ipotithete ise sti mia plevra aristera, ji ego sti mia plevra tou trapeziou dexia*)

4. a perspective other than the Director's, the Matcher's, or the structure's (Other heading), for example, "say the candle is facing the bucket, from the bucket it's on the left" (*pes oti to keri thori ton kouva, opos en o kouvas, aristera*).
5. a Neutral perspective capturing inter-object relations independent of a particular viewpoint, for example, "it's close to the bucket" (*en konta ston kouva*) or "they form a triangle" (*schematizun trigono*)
6. an Ambiguous perspective for expressions that could be interpreted as involving more than one of the above perspectives

Expressions from three more categories (Both-centered, Environment-centered, and Intrinsic; see Galati et al., 2013 for more information) collectively comprised less than 2% of all spatial expressions and will not be considered further.

Person-centered expressions were often implicit (65% of Director-centered expressions and 49% of Matcher-centered ones) and did not involve the use of personal pronouns (e.g., "it's on the left," *en aristera*). When classifying these implicit perspectives or other initially ambiguous cases, coders considered multiple sources of information, including the configuration of objects that Directors were describing, the respective viewpoints of the Director and Matcher, the prior discourse (e.g., if partners had explicitly agreed on a perspective), and the Director's array drawing (to establish the perspective from which Directors had organized objects in memory).

2.4.2. Reliability

The first author coded 20 pairs, while a second coder redundantly coded six pairs as well as the remaining four pairs. Prior to comparing their judgments, the coders discussed 52 instances for which there was disagreement over the segmentation of spatial expressions (i.e., cases where one coder identified a spatial expression while the other did not, or one coder parsed a phrase as two spatial expressions while the other did as one). All disagreements on segmentation were resolved by discussing them until consensus was reached. The remaining, nonredundantly coded dialogs were checked for consistent application of the agreed-upon criteria. For the 383 spatial expressions from the redundantly coded dialogs, the two coders made identical classifications 98% of the time, Kappa = .98, $p < .001$, exhibiting almost perfect agreement (see Landis & Koch, 1977).

3. Results

3.1. Spatial memory

Since Directors could be divided into those who drew arrays from perspectives aligned with the structure's axes (i.e., from an orthogonal viewpoint) and those who did so from a perspective oblique to the structure (specifically, from their study viewpoint of 225°), we first consider whether the distribution of the array drawings depended on the conditions at learning. We then turn to their JRD performance to corroborate that Directors indeed organized object relations in memory as indicated by their drawings' orientation.

3.1.1. Array drawings

We classified each drawing as being drawn from one of the orthogonal or oblique perspectives relative to the structure. Of the 24 drawings, 15 drawings were classified as being aligned and 9 as being misaligned with the structure's axes. Our Directors' aligned drawings were from three of the four orthogonal viewpoints: eight drawings from 0°, six from 180°, and one from 270°. All misaligned drawings were from 225° (see example in Fig. 3). Our categorization was checked against the rotation parameter (θ), indicating the degree the drawn configuration was rotated relative to the intrinsic structure of array.[4] To derive θ (and also the bidimensional regression coefficient, *BDr,* described below), we used Friedman and Kohler's (2003) bidimensional regression tool and recommendations to compare the Directors' drawings to the studied array, applying a Euclidean transformation to the veridical array coordinates.

We then examined the distribution of array drawings that were aligned with the structure (i.e., from one of the orthogonal viewpoints) versus misaligned with the structure (namely, from 225°) according to what Directors had known about their Matcher's viewpoint. Directors who studied the array while aligned with the intrinsic structure (from 0°) all used an axis of the structure as the organizing direction of their drawings (specifically, 0°), whether they knew the Matcher's viewpoint (135°) or not. On the other hand, as Table 1 shows, for Directors who studied the array while misaligned with its structure (from 225°), advance knowledge of their Matcher's viewpoint influenced the orientation of their drawings. When the Matcher's viewpoint was unavailable, they were more likely to use their study viewpoint (225°) to draw the array. But when they had known in advance that the Matcher was aligned with the array's intrinsic structure, they used the structure's axes as an organizing direction more frequently. When Directors had known

Table 1
Proportion and number of Directors who studied arrays from 225° and drew arrays as aligned with the intrinsic structure (from one of its orthogonal viewpoints) vs. from their own viewpoint, according to what they knew about their Matcher's viewpoint at study

	Drawing Aligned With Intrinsic Structure	Drawing Aligned With Study Viewpoint (from 225°)
Does not know Matcher's viewpoint		
Proportion	.25	.75
N	2	6
Knows Matcher is at 0°		
Proportion	.75	.25
N	3	1
Knows Matcher is at 135°		
Proportion	.50	.50
N	2	2

in advance that the Matcher would also be misaligned with the intrinsic structure (at 135°), half of the Directors opted for their study viewpoint and half used an axis of the structure as their organizing direction. The probability that the overall distribution of the drawings' orientation was observed by chance is small (p = .03, Fisher's exact test).

Finally, we examined the bidimensional regression coefficient (*BDr*) for each Director's drawings to ask whether the distortion in the relative positioning of objects, as reflected by *BDr,* would depend on the orientation of Directors' drawings. *BDr* estimates the goodness-of-fit between the drawings and the actual coordinates of the arrays, capturing unsystematic error in reconstructions when systematic biases are accounted for. Directors who had drawn arrays aligned with the structure drew arrays that were numerically less distorted than those who had drawn arrays misaligned with the structure, from their study viewpoint of 225° (arrays drawn aligned with structure: *BDr* = .99, *SD* = .02; arrays drawn misaligned with structure: *BDr* = .90, *SD* = .21). This difference was marginally significant according to an independent samples t-test on the Fisher-transformed *BDr*: t (22) = −1.91, p = .07. Advance knowledge of the Matcher's viewpoint did not reliably influence the distortion of the Directors' array drawings.

To summarize, the viewpoint from which Directors drew their arrays depended both on their own viewpoint at study and what they had known about their partner: Directors studying arrays from 0° strongly preferred that viewpoint, whereas those studying arrays from 225° varied in their preferences depending on what they had known about their Matcher's viewpoint. These Directors preferred more frequently their own viewpoint when they did not know where their Matcher would be, whereas they preferred more frequently an orthogonal viewpoint when Matchers were at 0°. This preference was reflected by the orientation of their drawings, which was confirmed by the rotational parameter θ. Arrays drawn from one of the orthogonal viewpoints of the structure (specifically, 0°, 180°, and 270°) were also somewhat less distorted than those drawn from the oblique viewpoint of 225°.

3.1.2. Directors' judgments of relative direction

To confirm that Directors had organized spatial locations in memory according to how they had oriented their array drawings, we analyzed their orientation and response latencies from the JRD task with their drawings' orientation (aligned vs. misaligned with the structure) as a between subjects factor, while ignoring the availability of their Matcher's particular viewpoint at study.[5] That is, we examined whether Directors who drew arrays aligned with the structure (in our corpus from 0°, 180°, 270°) and those who drew arrays misaligned with the structure (in our corpus from 225°) showed facilitation for that preferred direction.

As Fig. 4a and b illustrate, the Directors' orientation and response latencies were consistent with the preferred orientation of their array drawings. Directors who had drawn arrays aligned with the structure were generally faster to orient to and respond from headings aligned with the structure's orthogonal axes (0°, 90°, 180°, 270°) than from the oblique headings (45°, 135°, 225°, 315°). The reverse was the case for Directors who had drawn arrays from 225°. This led to a significant interaction between the heading from

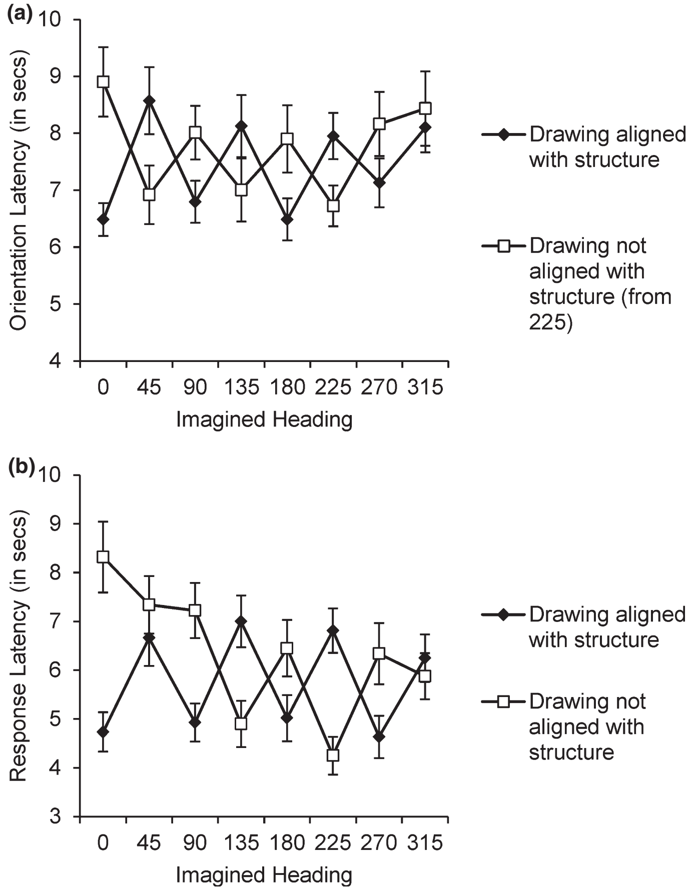

Fig. 4. Orientation latencies (a) and response latencies (b) in secs across imagined headings according to how Directors had drawn arrays.

which the array was drawn and the JRD trial's imagined heading for both orientation latencies, $F(7, 154) = 4.96$, $p < .001$, and response latencies, $F(7, 154) = 7.60$, $p < .001$. Directors' latencies differed significantly across imagined headings, both for those who drew the array aligned with the structure (orientation latencies: $F(7, 98) = 3.55$, $p < .01$; response latencies: $F(7, 98) = 4.58$, $p < .001$), and for those who drew the array from their study viewpoint of 225° (orientation latencies: $F(7, 56) = 3.19$, $p < .01$; response latencies: $F(7, 56) = 4.76$, $p < .001$).

We examined this sawtooth pattern of performance by fitting planned contrasts with weights: −1.625, .875, −0.625, 1.375, −1.625, 1.375, −0.625, .875.[6] For Directors who drew arrays aligned with the structure, this planned contrast with the minima at 0° and 180° described adequately their orientation latencies, $F(1, 14) = 10.34$, $p < .01$, accounting for 88% of the variance associated with the imagined heading and leaving a nonsignificant amount of variance unaccounted for ($p = .98$). The planned contrast also described adequately the response latencies of these Directors, $F(1, 14) = 21.14$, $p < .01$, accounting for 86% of the variance associated with the imagined heading and leaving a nonsignificant amount of variance unaccounted for ($p = .98$).

For Directors who drew arrays from their 225° study viewpoint, the sawtooth contrast with the minima at 225° and its counteraligned heading (45°) described adequately their orientation latencies, $F(1, 8) = 6.43$, $p < .05$, accounting for 62% of the variance associated with the imagined heading and leaving a non-significant amount of variance unaccounted for ($p = .82$). The planned contrast was marginally significant when applied to these Directors' response latencies, $F(1, 8) = 4.22$, $p = .07$.

Collectively, the orientation latencies and response latencies provide converging evidence that Directors organized the arrays in memory in a way consistent with how they had drawn them. Directors were generally faster to orient to and respond from headings aligned with their preferred direction and its perpendicular headings. This could mean that Directors represented the configuration from all the facilitated headings (McNamara, 2003) or that at retrieval they more easily adopted headings orthogonal to their preferred direction relative to oblique ones.

3.2. Spatial descriptions

Overall, Directors produced most frequently Neutral expressions in their descriptions (48% of all 1,609 spatial expressions), with Matcher-centered expressions constituting 20%, Director-centered 15%, Structure-centered 8%, ambiguous expressions 5%, and other headings 2% and of all expressions. Given our interest in how Directors adapted their descriptions according to the alignment of the intrinsic structure with either partner (and their advance knowledge of that), we focus our analyses on the distribution of those expressions of theoretical interest: Director-centered, Matcher-centered, and Structure-centered expressions. The distribution of these three types of expressions differed reliably, $F(2, 36) = 7.37$, $p < .01$, with Directors producing significantly fewer Structure-centered expressions than Director-centered, $F(1, 18) = 5.26$, $p < .05$, and Matcher-centered expressions, $F(1, 18) = 13.72$, $p < .01$.

The partners' alignment with the intrinsic structure influenced the distribution of these three types of expressions, $F(4, 36) = 3.96$, $p < .01$. This interaction was driven by Directors using more Matcher-centered expressions than Director-centered ones (38% vs. 2%) when the Matcher was aligned with the structure (95% CI [−.56, −.15], $p < .01$), and numerically more Director-centered expressions (14% vs. 25%) when they were the ones aligned with the structure (95% CI [−.09, .32], $p = .27$).

When Matchers were aligned with the intrinsic structure during the description, the Matcher's perspective dominated Directors' descriptions whether it was available in advance or not. As Fig. 5a and 5b illustrate, when Matchers were at 0°, Directors adopted predominately their partner's perspective, using significantly more Matcher-centered than Director-centered (95% CI [.15, .56], $p < .01$) or Structure-centered expressions (95% CI [.18, .56], $p < .01$). This preference for Matcher-centered over Director-centered expressions was reliably significant when Directors hadn't known in advance that Matchers

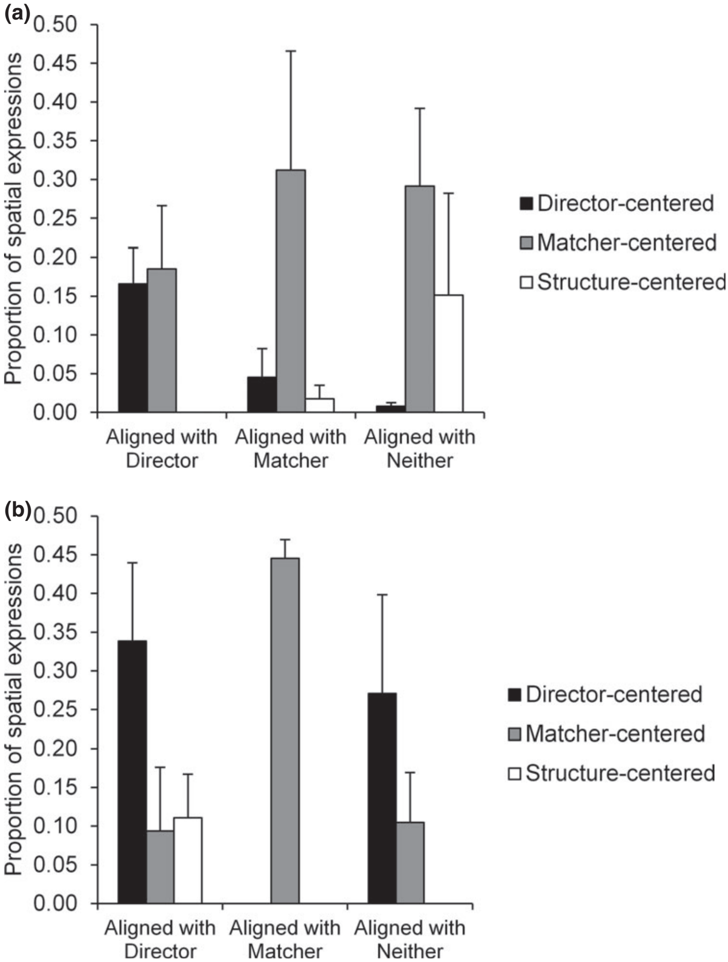

Fig. 5. Proportion of Director-centered, Matcher-centered, and Structure-centered expressions when the Matcher's viewpoint was available (a) or unavailable (b) at study, across the three conditions of alignment with the intrinsic structure: when the structure is aligned with the Director (i.e., Director at 0°, Matcher at 135°), when the structure is aligned with the Matcher (i.e., Director at 225°, Matcher at 0°), and when the structure is aligned with neither partner (i.e., Director at 225°, Matcher at 135°).

would be at 0° (45% vs. 0% of 144 expressions, 95% CI [−.74, −15], $p < .01$) and marginally so when they had known it in advance (31% vs. 5% of 161 expressions, 95% CI [−.56, 03], $p = .07$).

Advance knowledge of the Matcher's viewpoint at learning did not influence reliably the distribution of the three types of spatial descriptions, $F(2, 36) = 1.83$, $p = .18$. Despite this lack of an interaction, Directors who had known the Matcher's viewpoint in advance did use fewer Director-centered than Matcher-centered expressions overall (7% vs. 26% of 763 expressions; 95% CI [−.36, −.02], $p < .05$). The distribution of expressions when neither partner was aligned with the intrinsic structure also exemplifies this shift away from an egocentric stance when the partner's viewpoint was known. As illustrated by the black bars across Fig. 4a and b, Directors who had known in advance that Matchers would also be misaligned with the intrinsic structure used fewer Director-centered expressions than when they had not known in advance (1% vs. 27% of 813 expressions, 95% CI [.05, .47] $p < .05$) and, as illustrated by the white bars, used numerically more Structure-centered descriptions (15% vs. 0%, 95% CI: [−.33, .02], $p = .08$). A similar, albeit not reliable, shift away from an egocentric stance was also observed when Directors were aligned with the intrinsic structure. Directors at 0° who had not known at study that Matcher's would later be at 135° (Fig. 5b) used numerically more egocentric expressions (34% Director-centered vs. 10% Matcher-centered of 253 expressions; 95% CI [−.05, .54], $p = .10$), whereas those who had known in advance (Fig. 5a) used comparable proportions of egocentric and Matcher-centered expressions (17% Director-centered vs. 18% Matcher-centered of 238 expressions; 95% CI [−.31, .27], *n.s.*).

Finally, to examine whether the Directors' prior memory organization influenced their descriptions, we conducted analyses that included as a factor the perspective from which Directors had drawn the arrays (and thus the preferred direction of their memory representations, as confirmed by JRD performance). On its own, the alignment of the Directors drawings did not influence reliably the distribution of Director-centered, Matcher-centered, and Structure-centered expressions they had used, $F(1, 15) = 1.23$, $p = .29$. However, in pairs with neither partner aligned with the structure, the distribution of the Directors' expressions did differ depending on the alignment of their drawings: those who had drawn arrays aligned with the intrinsic structure used significantly more Structure-centered expressions than those who had drawn arrays from 225° (30% vs. 0%, 95% CI: [.12, .48], $p < .01$). This led to a significant three-way interaction between the type of expression, the alignment of the Directors' drawings, and the relative alignment of the partners during the description, $F(2, 30) = 4.43$, $p < .05$.

Three main conclusions emerge regarding the Directors' descriptions. First, the extent to which speakers described arrays from their own viewpoint, their partner's viewpoint, or by referring to the layout's intrinsic structure depended largely on the two partners' alignment relative to the intrinsic structure during the description. When the intrinsic structure was aligned with the partner, speakers used overall more partner-centered expressions, even when they hadn't known this in advance. Second, knowing the partner's viewpoint in advance reduced the use of egocentric expressions relative to partner-centered ones in some circumstances. This was the case when neither partner was aligned with the intrinsic structure (and marginally so when the speaker was). And third, speakers did not plan their descriptions solely based on their memory representations; the preferred direction of speakers' memory did not influence reliably the distribution of expressions they used. However, when neither partner was aligned with the intrinsic structure, speakers were more likely to refer to the structure in their descriptions when they had used an axis of the structure as an organizing direction in memory.

4. Discussion

Our findings demonstrate that people combine multiple cues, including representational and social ones, to guide their spatial perspective-taking behavior. As we describe in more detail in the following sections, a clear picture emerges: People consider jointly various cues, whether these are available a priori or become perceptually available during the interaction, weighing them according to their salience and relevance to the task. They select the perspective that is most reinforced by these cues to organize spatial information in memory or to describe this information. As we will argue, people do so because, in the context of joint tasks, they appraise that a perspective reinforced by multiple cues is optimally effective for minimizing their collective effort.

4.1. People use multiple cues to select the preferred direction of their spatial memories

In our study, the preferred direction around which people organized spatial relations in memory depended on whose viewpoint was reinforced by the orientation of the configuration's intrinsic structure. This was reflected in how Directors had drawn their arrays. When Directors had studied the layout while aligned with its intrinsic structure, they defaulted to using their own viewpoint as the organizing direction, regardless of whether they knew their partner's subsequent viewpoint. On the other hand, when Directors had studied the layout while misaligned with its intrinsic structure, knowing their Matcher's subsequent viewpoint relative to the intrinsic structure influenced the organization of their memories: They were more likely to use one of the structure's axes (vs. their study viewpoint) as an organizing direction when they knew that the Matcher would subsequently be aligned with the intrinsic structure, whereas they were more likely to use their study viewpoint (vs. an axis of the structure) when they didn't know their Matcher's subsequent viewpoint. When They knew that the Matcher would also be misaligned with the structure, Directors were equally likely to exploit the structure's axis and to use their own viewpoint as an organizing direction.

The performance of Directors in the JRD task corroborated that the organizing direction of spatial relations in memory was in line with the orientation of their drawings. Directors who drew arrays from one of the structure's orthogonal axes were faster in JRDs to orient to and respond from headings aligned with the structure's orthogonal axes (0°, 90°, 180°, 270°). Similarly, those who drew arrays misaligned with the structure, from their study viewpoint of 225°, showed facilitation in orienting to and responding from that viewpoint (and for 315°, 45°, 135°). The orientation and response latencies of each group of Directors suggest that they either represented all facilitated orientations (McNamara, 2003), or else that headings orthogonal to their preferred direction were more easily adopted at retrieval than oblique ones. Further research could distinguish these two possibilities. For our purposes, the most pertinent point is that performance in JRDs demonstrated facilitation for the preferred direction indicated by the Directors' drawings. Together, the findings of both memory tasks underscore that the alignment of a given partner with the intrinsic structure affords sufficient pragmatic motivation to organize spatial relations from that viewpoint: When the orientation of the intrinsic structure converges with a partner's viewpoint, it motivates its use as the preferred direction in memory.

This contextualizes our earlier findings that, when no intrinsic structure is available, people may encode the partner's viewpoint in memory but not necessarily use it as an organizing direction (Galati et al., 2013). When studying a randomly configured layout, organizing spatial relations around the partner's viewpoint is likely costly and unnecessary if speakers can interact freely (cf., Shelton & McNamara, 2004). With such insufficient motivation to invest in organizing spatial relations from the partner's available viewpoint, it makes sense that speakers in Galati et al. (2013) simply encoded the partner's viewpoint, since they could use this information later as needed.

Other studies have shown that people *can* use a nonegocentric perspective as an organizing direction in memory, upon explicit instruction. Instructions to learn an array from a nonegocentric perspective in a noninteractive task (Greenauer & Waller, 2008) or to describe a layout from another's perspective in an interactive task (Shelton & McNamara, 2004) have been effective in setting a nonegocentric preferred direction in memory. Here we show that, even in the absence of such explicit instructions, people can *spontaneously* adopt a nonegocentric perspective as an organizing direction, at no apparent cost, when it is supported by additional cues. Thus, although the mere availability of the partner's viewpoint may on its own be an insufficient cue to set the preferred direction of spatial memories (Galati et al., 2013), it can be sufficient in other contexts, as when reinforced by another relevant cue, such as the configuration's intrinsic structure.

Our present findings, in line with those of Mou and McNamara (2002), demonstrate that the intrinsic structure contributes to organizing spatial relations from a nonegocentric viewpoint. However, our findings also differ in some ways. In that study, participants overall opted to use the intrinsic structure as their preferred direction in memory even when converging cues from the environmental structure were removed (by placing the layout within a circular room). In our study, participants did not always opt for the intrinsic structure's axes as an organizing direction (see also Richard & Waller, 2013). In fact, the majority (75%) of participants who studied the array from 225° without knowing their partner's viewpoint (which could have highlighted the intrinsic structure) opted for their own, egocentric viewpoint. This discrepancy between our findings and Mou and McNamara's (2002) may suggest that, rather than giving precedence to particular cues in spatial reasoning—with the intrinsic structure, for instance, being most dominant—people weigh multiple cues probabilistically, according to task-specific demands, in order to determine their preferred reference frame. As we point out next, this probabilistic weighing of cues is relevant not only for encoding spatial information in memory but also for describing it.

4.2. People adapt their memories and descriptions with the aim of minimizing their collective effort

We consider the partner's viewpoint and the intrinsic structure of spatial configurations to be among those relevant cues that contribute to the selection of a spatial perspective in joint spatial tasks. Our view is that this selection is made consistently with *the principle of least collaborative effort* (Clark, 1996; Clark & Wilkes-Gibbs, 1986)—the proposal that people share responsibility for mutual understanding, and try to maximize their efficiency of coordination and minimize their collective effort. By this principle, when the intrinsic structure converged with the partner's viewpoint, speakers likely appraised that it would be most efficient to adopt that perspective in later descriptions; they were thus willing to invest the cognitive effort at study to encode spatial relations from that non-egocentric perspective. Conversely, when the intrinsic structure converged with the speakers' own viewpoint, they likely appraised that it would be most efficient to use that perspective in the subsequent collaboration, and thus did not incorporate their partner's viewpoint in their memory representations.

Appraisals about the relative cognitive burden of each partner in the task influenced not only the preferred direction around which speakers organized spatial information in memory, as discussed in the previous section, but also how they actually described this information. When the orientation of the intrinsic structure converged with their partner's viewpoint, speakers alleviated their partner's cognitive burden by describing spatial relations from the partner's viewpoint. When the orientation of the intrinsic structure converged with the speakers' own viewpoint, speakers tended to describe spatial information from their own perspective, with their partners having to unpack the spatial mappings of those egocentric descriptions. Thus, for both their memory organization and their descriptions, speakers flexibly adopted the perspective reinforced by converging cues, presumably because they considered this perspective to be optimal for minimizing their collective effort.

Before addressing how our work extends *the principle of least collaborative effort*, we turn to two pertinent questions. First, *when* is spatial perspective-taking in fact most computationally demanding for a language user? And second, is the speakers' adaptation in fact effective at minimizing their collective effort?

With respect to the first question, our findings offer a caveat to earlier demonstrations that, in spatial tasks, misalignment determines a language user's cognitive demands (e.g., Duran et al., 2011; Mainwaring et al., 2003; Schober, 1993, 1995). Here, when Directors were at 0° and Matchers at 135°, Directors overall opted for their own perspective in descriptions, presumably because reasoning from an oblique perspective was computationally more difficult (support for the relative difficulty of adopting the oblique 135° offset also comes from Galati et al., 2013). However, when Matchers were at 0° and Directors at 225° (also a 135° offset), Directors readily opted for their partner's perspective in descriptions. This illustrates that misalignment on its own does not determine spatial perspective choices; people do not simply perform mental rotation in order to consider their partner's viewpoint. Instead, by considering their partner's misaligned viewpoint along with other cues, they make attributions about their respective ability to contribute to advance the goals of the task (see also Duran et al., 2011).

With respect to the second question, in other work, we have examined specifically whether speakers' perspective choices are in fact successful at minimizing pairs' collective effort, as indicated by performance outcomes (Galati & Avraamides, 2013). By examining the number of conversational turns that pairs from the present corpus took to complete the task and the degree of distortion in their tabletop reconstructions, we confirmed that speakers' description strategies generally facilitated coordination. For instance, when Matchers were aligned with the intrinsic structure, which was when Directors used predominately Matcher-centered descriptions, interactions were the most efficient in terms of conversational turns relative to the other alignment conditions. Moreover, Matchers reconstructed more accurate (i.e., less distorted) layouts as Directors used greater proportions of Matcher-centered expressions. Since in that condition it was presumably easier for Matchers to interpret descriptions from their own perspective, the Directors' description strategy turned out to be successful in terms of improving both efficiency and accuracy.

In our view, the extent to which speakers' perspective choices are effective at improving performance outcomes depends on how these outcomes are weighted by the task's goals and constraints. The available cues (e.g., partner's viewpoint, the intrinsic structure of the configuration), the affordances of the communicative situation (e.g., lacking visibility of each other's work stations), and the goals of communication (e.g., aiming for an accurate reconstruction) influence, along with speakers' perspective choices, the criterion that partners adopt to reach the mutual belief that they have understood each other well enough for their purposes. Depending on this "grounding criterion" (Clark & Brennan, 1991), an effective strategy may in some circumstances dissociate performance outcomes (e.g., accuracy and efficiency), if these dimensions are weighted differently by the task's goals.

The present work further qualifies the *principle of least collaborative effort* by highlighting that speakers consider the goals, affordances, and available cues of the task, *across all of its phases*, in order to select the "optimal" perspective. Speakers gauge their own and their partner's cognitive effort for each phase of the joint task (e.g., when encoding the information and when describing it), using all the information they have available. This enables them to determine whether investing additional effort at an early stage would yield savings during the subsequent coordination. Such considerations are relevant to several real-world scenarios in which speakers first have to commit certain spatial information to memory and convey it to someone else at a later point (e.g., studying a map as a co-pilot on a road trip to memorize the planned route and give directions from memory later to the driver).

When Directors in our study knew in advance that their partner's viewpoint would be aligned with the layout's intrinsic structure, they were more likely to adopt an axis of the structure as an organizing direction at encoding, presumably because they anticipated this would make the planning of spatial descriptions easier during the interaction. In other tasks, in which speakers do not have to retrieve spatial layouts from memory, but rather have visual access to them as they are describing them (e.g., Schober, 1993, 1995; Shelton & McNamara, 2004), this initial investment of effort may not be a relevant concern. Nevertheless, these speakers still select their preferred perspective on the basis of task-dependent constraints of the description phase (e.g., *Does the addressee know where I am or not? Is the addressee aligned or misaligned with me?*), and accommodate for their partners when they perceive them to be limited, consistently with the principle of least collaborative effort. As we expound on in the next section, speakers take into account both a priori and perceptually available information when planning and executing a joint task. This may sometimes involve revising a strategy (e.g., an initially preferred perspective) in light of information emerging at a new phase.

4.3. People use both a priori and perceptually available cues in spatial perspective taking

When speakers select the perspective from which to describe information, they use not only social and representational information available in advance but also information that is perceptually available in the communicative setting. In the present study, speakers did not merely rely on the organization of their memories when describing spatial layouts. In fact, the distribution of speakers' spatial expressions did not reliably depend on their preferred direction in memory (as reflected by their array drawings). For instance, Directors who studied the array from 225° without knowing their Matcher's viewpoint used overwhelmingly Matcher-centered descriptions when interacting with a Matcher at 0°, even though most of them had used their own viewpoint as the preferred direction of their memories.

The flexible use of a priori and perceptually available information is consistent with findings that, in describing spatial relations, people do not always adhere to their memory's organizing direction when it conflicts with perceptual evidence; instead, they can use both sources of information to select the perspective of their descriptions (Galati et al., 2013; Li et al., 2011). This is congruent with our earlier point that in dynamic, multi-phase tasks, conversational partners estimate their relative cognitive demands across all stages of the joint task, using all information they have available at a given stage and updating their perspective-taking strategies along the way.

The prior organization of Directors' memory representations seemed to influence descriptions primarily when neither partner was aligned with the intrinsic structure: Those who had organized spatial relations according to the structure's axis used structure-based descriptions more frequently than those who had organized relations from their own viewpoint (225°). Knowing in advance that neither partner would be aligned with the intrinsic structure may have underscored the bilateral axis of symmetry across which both partners were juxtaposed. Thus, considering at study the partner's misaligned perspective in the context of intrinsic spatial cues can highlight nonegocentric perspectives for organizing information.

Although in our study, we have focused on a priori information concerning the partner's spatial viewpoint, other a priori information about the partner may have also influenced speakers' descriptions since pairs here were friends. Shared knowledge could have increased Structured-centered descriptions through references to shared spatial schemas (e.g., shared familiarity with the game "tic-tac-toe," which was referred to by a few pairs). Or, based on prior experience, speakers may have been better able make accurate attributions about their partner's spatial abilities, and thus tailored their descriptions accordingly (see Schober, 2009, for evidence that pairs adapt the perspective of their descriptions according to their relative spatial abilities). On the other hand, in light of findings that speakers are more likely to make egocentric errors with friends due to overestimating that their friends know what they know (Savitsky, Keysar, Epley, Carter, & Swanson, 2011), speakers here may have been more likely to organize information in memory egocentrically or to describe spatial layouts from their own perspective. Even though it is possible that speakers in our study described information somewhat differently than they would have with partners who were strangers (e.g., referring to more spatial schemas or being more egocentric), they still adapted their description choices flexibly, according to their relative alignment with the intrinsic structure and their advance knowledge of that. For instance, egocentric descriptions were reduced when speakers knew their partners' viewpoint in advance and were almost absent when the partner's viewpoint was aligned with the intrinsic structure. Thus, although friendship as a social cue may have influenced perspective-taking, it did not trump the influence of other social and representational cues.

4.4. *Toward a framework for flexible perspective-taking*

As we have seen, when selecting the perspective from which to encode or describe spatial information, people consider a confluence of different sources of information—social, egocentric, and representational. The adaptation we document in spatial perspective-taking underscores that people use all information as soon as it becomes available, in whichever phase of the joint task (whether at study or at collaboration), weighing them according to their salience and their relevance to the task's goals to make attributions about their respective ability to advance the task. Thus, when a representational cue, such as the intrinsic structure, converges with the speaker's learning viewpoint, the speaker will opt for that egocentric viewpoint; when the intrinsic structure converges with a social cue, such as the partner's viewpoint, the speaker will opt for the partner's viewpoint. Thus, social cues can shape not only the interpretation of spatial descriptions (Duran et al., 2011) but also the production of spatial descriptions and, critically, the underlying memory representations supporting those descriptions (cf. Hölscher et al., 2011; Mainwaring et al., 2003; Schober, 1993, 1995, 2009).

Speakers do not invariably default to their egocentric perspective, whether for encoding or for describing spatial information, as the proposal of Keysar and his colleagues would predict (Horton & Keysar, 1996; Keysar, Barr, Balin et al., 1998; Keysar, Barr, & Horton, 1998). Instead, our findings suggest that what constitutes the "easiest" or "optimal" perspective for speakers to adopt is not defined solely in terms of egocentric experience, but rather in terms of the convergence of multiple, relevant sources of information. These sources of information are taken into consideration as soon as they become available in the task and not as a late adjustment to repair misunderstandings.

This is in line with the view that information from different sources—including the shared environment with conversational partners, discourse context, and within-sentence structural, and lexical biases—are integrated probabilistically and in parallel to shape behavior (e.g., Jurafsky, 1996; MacDonald, 1994; Tanenhaus & Trueswell, 1995). Thus, when information about the conversational partner's needs is available early enough and is represented simply (see Brennan & Hanna, 2009; Galati & Brennan, 2010; Hanna, Tanenhaus, & Trueswell, 2003), it is weighted alongside other relevant constraints and enables speakers to tailor their behavior appropriately. In collaborative spatial tasks, this information includes the partner's location in space, which in combination with other cues—properties of the objects, the intrinsic structure of the layout and the surrounding environment, the speaker's egocentric viewpoint, and explicit instructions—leads to inferences about the relative difficulty of reasoning from that perspective.

We take the adaptation we report here to reflect the general flexibility of the cognitive system, rather than to be specialized for spatial perspective taking. The principles guiding how people consider their conversational partner's spatial perspective—of using multiple sources of information, of using information whenever it becomes available, of aiming to minimize collective effort—are not unlike those guiding how they consider their partner's conceptual construal, their knowledge, or agenda (see Schober, 1998).

In sum, in collaborative spatial tasks, people adapt both their memory representations and linguistic behavior flexibly, in nuanced ways. They take into account converging social and representational cues, whenever they become available—whether through advance information or perceptual evidence—to appraise whose perspective would be optimal for coordinating most efficiently. This joint consideration of multiple cues influences whether people encode their partner's available viewpoint in memory and whether they adopt it in descriptions.

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Notes

1. Note that two-thirds of the Directors who studied arrays without knowing their Matcher's subsequent viewpoint were actually in the same situation, even if their circumstances at the description phase differed: They studied arrays at 225°, whether they later described the array to a Matcher who was at 0° (*Aligned with Matcher*) or at 135° (*Aligned with Neither*). Thus, the organizational preferences of these Directors as indicated by their memory tests, which preceded descriptions, were considered together (see Table 1).
2. There were no reliable effects involving gender. In the JRD task, orientation and response latencies did not differ significantly between male and female Directors.

Also, gender did not interact with performance across headings. In descriptions, the distribution of spatial expressions that Directors used was not influenced by the gender combination of the pairs or the gender of the Director; neither the main effect nor the interaction of each these factors with the type of spatial expression was significant.

3. We also recorded pointing error in JRD responses—the unsigned angular deviation of the joystick response from the veridical response. Pointing error demonstrated the same sawtooth pattern of performance obtained for orientation and response latencies (Fig. 3), although it was not reliable. There were somewhat high pointing errors ($M = 64.56°$, $SD = 65.33°$), despite the lack of a speed accuracy tradeoff. Although, within participants, latency-error correlations did differ significantly from zero (for orientation latencies: t (23) = 2.55, $p < .05$; for response latencies: t (23) = 2.10, $p < .05$), these were in the opposite direction than that expected by a speed accuracy trade off (for orientation latency the mean Pearson's $r = .06$, $SD = .12$; for response latency Pearson's $r = .05$, $SD = .12$). As we pointed out in Galati et al. (2013), the high pointing errors are likely an artifact of joystick mechanics biasing responses away from the intended bearing. Because the joystick shaft moves within a square base, reproducing angles at diagonals (i.e., 45°, 135°, 225°, and 315°) is easier than other angles.
4. Drawings classified as being drawn from 0° had a mean θ of 0.58° ($SD = 1.08°$), those classified as being drawn from 180° a mean θ of 190.37° ($SD = 22.04°$), those classified as being drawn from 225° a mean θ of 227.17° ($SD = 9.24°$), and the drawing classified as being drawn from 270° had a θ of 269.59°. The perspective assigned to each drawing was indeed correlated highly with the drawing's corresponding rotation parameter (θ), Pearson's $r = .99$, $p < .001$.
5. Initially, we had analyzed performance on the Judgments of Relative Direction task while ignoring the organization suggested by the Directors' drawings. Those results were obfuscated by the fact that when studying arrays from 225°, Directors sometimes opted for their own viewpoint and other times opted for one of the axes of the intrinsic structure as their preferred direction (as shown in Table 1).
6. To examine this sawtooth pattern of facilitated performance, other researchers (e.g., Greenauer & Waller, 2008) have used custom contrast weights with only one minimum value (e.g., −0.625, 1.375, −0.625, 0.375, −1.625, 0.375, −0.625, 1.375). We adapted these weights to represent a pattern with two minima, upon reasoning that in our study all but one of the Directors who had drawn arrays aligned with the intrinsic structure did so either from 0° or 180°.

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