How Frames of Reference Prime Spatial Memory

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Abstract

This study examined priming spatial memory by frames of reference. Participants verified verbal descriptions of scenes which depicted spatial relations among objects. The intrinsic and relative frames of reference were used in the descriptions with varying degrees of veridicality. Descriptions in the two reference frames could either be equally distributed in terms of validity (50:50 ratio of true vs. false description) or were biased towards one of the two spatial frames. Participants were found to be sensitive not only to the spatial frame prime at the lower level of individual descriptions but also at the more global level of overall reliability of the two descriptive schemas. These findings provide direct evidence that spatial frames of reference can influence spatial memory and that this influence depends on how frequently a frame of reference is associated with valid and reliable information.

Keywords: spatial frames of reference; spatial memory.

Introduction

Spatial frames of reference (FoR) are ways of organizing mentally and communicating verbally certain aspects of our spatial knowledge. They represent coordinate systems used to compute and specify the location of objects with respect to other objects. For example, the mutual positioning of the three objects depicted in Figure 1(a) can be described in several ways in English depending on which object's location is in the focus of our mental attention and our communicative intention, i.e., which object is the located object, or locatum, and which other object in this visual scene is selected as the reference object, or relatum. Such verbal descriptions typically entail a choice of a spatial frame of reference. For example, (i) below is a description of the relationship between the star as the locatum and the truck as the reference object in the intrinsic frame of reference while (ii) is a description of the relationship in the relative frame of reference:

(i) The star is behind the truck.
(ii) The star is to the right of the truck.

An intrinsic frame of reference is object-centered while a relative frame of reference is viewer/speaker dependent, also construed as egocentric. There is one further possibility — describing the relationship in an absolute frame of reference, independent of viewing position, etc., using some kind of fixed bearings, as in (iii) below, in this example, cardinal directions:

(iii) The star is to the North (East, etc.) of the truck.

For the purposes of this study, the distinction between intrinsic and relative frames of reference is important as these two constitute the more common and habitual ways of describing spatial relationships that do not involve large-scale space, both in English and in the language studied here, Bulgarian, as well as in most other European languages. The terminological distinction between intrinsic and relative FoRs follows from the tri-partite typological scheme developed by Levinson and colleagues (Levinson, 2003).

Research in the last decades has uncovered considerable variation in the use of spatial frames of reference both across cultures and within individuals. Languages and cultures differ in the degree to which one, two, or all three of these frames of reference are available as a means of description (for a brief summary, see Majid et al., 2004). Spatial language processing on an individual level can be affected by a number of features of the communicative situation (Schober, 1993, Goschler, Andonova, & Ross, 2008, Andonova, 2010), the nature of the objects in the spatial scene and their relationship, for example whether there is a functional component in addition to the geometric aspects of the relationship (Carlson-Radvansky & Radvansky, 1996, Coventry & Garrod, 2004, Andonova, Tenbrink, & Coventry, 2010), as well as other considerations. Features of the objects themselves also direct attention to the use of different reference frames, for example, when an object has no salient axis such as a cube or a sphere, it is not common to employ the intrinsic frame (Landau, 1996). Whether and how others are perceived to be interacting with the objects described can also lead to the use of different kinds of relative reference frames (Tversky & Hard, 2009).

Among the communicative features that influence choices of frames of reference are interlocutors' identity, conversational roles, and previous verbal descriptions employed by oneself or by others in the communicative exchange (Schober, 1998; Watson, Pickering & Branigan, 2004). Similar effects of interlocutors and their descriptive choices are also found with spatial perspective (egocentric vs. allocentric, route vs. survey perspective, etc.). In a series of confederate paradigm experiments on describing routes on schematic maps, choice of spatial perspective was influenced by the use of perspective of the dialogic partner, both before and after they switched perspective (Andonova, 2010). Perspective priming did not occur, however, when partners used perspective inconsistently. How and why spatial language choice is affected by previous descriptions is still debatable, in particular, the degree to which such effects are consistent with explanations via automatic low-level priming mechanisms (Pickering & Garrod, 2004) vs. alignment or coordination of representations with a stronger strategic element (Clark, 1996), or a combination of both (Branigan, Pickering, Pearson, & McLean, 2010).

Does choice or availability of frames of reference, however, play a role in cognitive processes beyond language use? Variation in language use of frames of reference has been indicated to associate with, if not lead to, cross-linguistic and cross-cultural differences in spatial reasoning and in tasks involving memory for the spatial configuration of objects, for motion trajectories and path-direction (Majid et al., 2004, Haun, Rapold, Janzen, & Levinson, 2011). Such studies indicate that different non-linguistic FoRs are used to accomplish similar tasks and cognitive goals, and that these non-linguistic FoRs align with the preferred FoR of the language spoken by the people executing the reasoning and spatial memory tasks. However, such Whorfian effects and explanations have met with criticism (Li & Gleitman, 2002) and are far from being clearly established. The question remains whether different spatial frames of reference may exert an influence in non-linguistic cognitive tasks and to what degree, if so.

The literature on spatial memory has examined the distinction between two frames of reference in spatial memory (for example, Mou & McNamara, 2002, Nardini, Burgess, Breckenridge, & Atkinson, 2006). One type of representation is egocentric in that it encodes an object's relation to the agent/self, and the other is allocentric and encodes a location with respect to an external frame of reference such as would be provided by landmarks, for example. Mou & MacNamara (2002) have provided evidence that spatial memories are organized around intrinsic (object-derived) frames of reference, which are selected on the basis of egocentric experience and environmental cues. Using the array rotation paradigm, Nardini et al. (2006) traced the developmental trajectories for use of different reference frames in spatial memory in children between 3 and 6 years of age and found that the viewpoint-independent recall based only on the array and its nearby landmarks emerged relatively late at around 5 years. Furthermore, this later-developing ability utilizing object-referenced (intrinsic) representations was not found to depend on verbal encodings. All in all, studies have underlined the role of intrinsic representations in spatial memory.

Less is known, however, about the relationship between verbal descriptive choices in terms of frames of reference and subsequent memory for the spatial relationships described. Can the frame of reference used in naming a spatial relationship affect memory for it? To the best of our knowledge, the possible influence of the frames of reference as a descriptive choice on the accuracy and/or flexibility of spatial memory has not been examined systematically. In fact, it is common for spatial memory studies to exclude the influence of verbalization as an extraneous variable. On the other hand, verbally labeling entities and relationships may enhance subsequent memory episodes and verbalization may occur even if not required explicitly. Spatial frames of reference may prime memory related behaviors. This was one of the main driving forces behind the research reported here.

A second basis for motivation of this research is related to investigating how people make choices between two schemes of description in a way that is not only flexible but also sensitive to and informed by the relative probabilities of success associated with the use of one or the other. For that reason, we introduced diverging degrees of veridicality associated with individual frames of reference as part of the experimental design. Participants studied a series of visual scenes involving three objects in a certain spatial relationship and verified a verbal description of the visual scene that was expressive of either an intrinsic or a relative frame of reference. In addition, the description was either a truthful and valid description of the scene or a false (invalid) description within the given frame of reference. The important manipulation here was that participants were randomly assigned to one of three possible Bias conditions. In all three conditions, half of the descriptions were in the intrinsic frame of reference and the other half were in the relative frame of reference. In the neutral or baseline condition, each of the two frames was associated with the same equal probability of being valid or invalid, i.e., half of the intrinsic descriptions were valid descriptions of the relationship in the scene, and the other half were invalid. The same 50:50 ratio applied to the alternative relative frame of reference. However, the other two conditions were not neutral but contained a positive bias towards one of the frames and a negative bias towards its alternative. This was achieved by manipulating the validity of the descriptions as explained below in the Method section.

Method

The experimental design included three independent variables: Frame of reference for the verbal prime (Intrinsic vs. Relative), Veridicality of the statement (True or False), and Bias condition (No bias, Intrinsic FoR Bias and Relative FoR bias). The two dependent variables were based on participants' responses to the study phase (verification accuracy) and the test phase (placement choice) of the experimental procedure. Placement in the test phase was in one of two positions, a binary choice of placement consistent either with the intrinsic FoR or with the relative FoR, and the ratio of choosing a position with the intrinsic FoR was used as the dependent measure (Fig. 2).

Three hypotheses were derived in relation to the experimental variables. First, the placement choices in the test phase for individual visual scenes were expected to be affected by the spatial frame of reference encountered for the scenes during the study phase. Second, we reasoned that the veridicality of description in the study phase would also leave a trace on participants' placement choices in that valid descriptions in a given frame of reference during the study phase could be more easily recalled and used in the placement choices during the test phase than invalid ones. Finally, we hypothesized an interaction between the frame of reference of the prime in the study phase and bias condition as a variable. Given that the intrinsic and relative frames of reference were designed here to be associated with different degrees of veridicality, the priming influence of the specific frame of reference used could be weaker or stronger depending on the reliability of the reference frame.

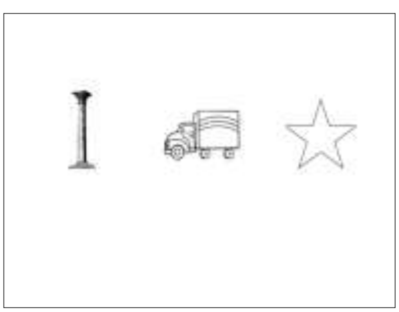
Participants

28 participants (12 men and 16 women) took part in the experiment. They were university students between the ages of 20 and 35 years old who were volunteers and/or participated in exchange for course credit. Their mean age was 26.68 years. All were native speakers of Bulgarian.

Stimuli

The stimuli consisted of 32 target and 5 practice items. An item comprised a simple sentence (a verification statement) followed by a visual scene. The statement described the position of the *locatum* with respect to the reference object (*relatum*) and the visual part of the stimulus depicted three objects placed linearly in such a way that the two lateral objects were at an equal distance from the central object. The central object was the reference object, or *relatum*, and one of the two lateral objects was the *locatum* whose position relative to the relatum was in the focus of the statement. The statements and visual scenes were shown in a series on the screen in a slide show. For example, below are two items each consisting of a statement followed by the visual scene it refers to (Fig. 1).

(a) The star is behind the truck.



(b) The balloon is to the left of the goat.

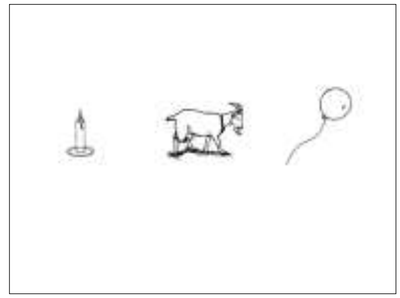
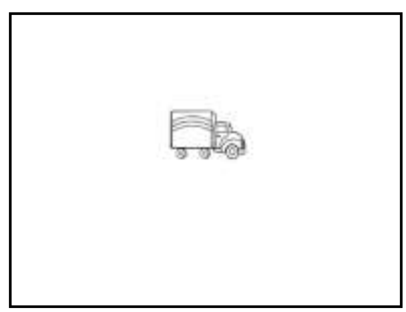


Figure 1: Examples of image stimuli with the preceding statement which could be either true (a) or false (b).

The three objects in the scenes were selected in the following way. The central object was either an animal or an inanimate object (vehicles, chairs, etc.) that had a clear front-back axis asymmetry so that statements phrased in the intrinsic FoR could be validated. The other two objects, on the other hand, had no clear fronts, backs, or sides, i.e., for the purposes of this study they were non-axial. They did have a clear vertical axis which, however, was irrelevant here. All scenes depicted the three objects as simple line drawings in a similar style as illustrated above; the objects had simple common names.

The stimuli for the test phase were derived from the original visual scenes from the study phase and involved three differences. There were no objects present in the scene except for the central object, i.e., the reference object (relatum) which was placed with the opposite orientation, facing in the opposite direction. The sentences lacked the spatial terms but preserved the same objects named as in the study phase. For example, the test phase stimuli for the examples in Figure 1 above were those depicted in Figure 2 below.

(a) The star ----- the truck.



(b) The balloon ----- the goat.

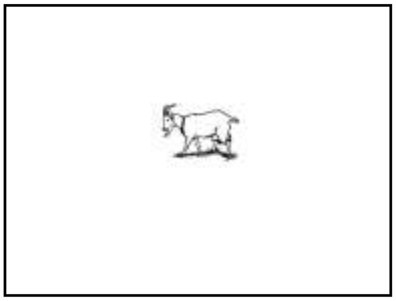


Figure 2: Examples of image stimuli with the preceding textual prompt in the test phase.

For the purposes of this experimental design, twelve stimuli lists were constructed, four for each of the three Bias conditions. The 32 target stimuli (sentence-picture pairs) were placed in a pseudo-randomized order in each of them with constraints on the number of stimuli in direct succession that had the same Prime spatial frame, the same value for animacy, orientation of the central object, etc. No scene was repeated within any of the lists and no locatum object was included in the target scenes more than once.

The four lists for the neutral baseline condition contained an equal number of stimuli in each of the two frames and degree of veridicality was even distributed across the two frames. The lists in the Intrinsic bias condition contained 16 descriptions in the intrinsic frame 12 of which were valid (veridical) and the remaining four were invalid (false). They also contained 16 descriptions in the relative frame only 4 of which were valid and the remaining 12 were invalid, thus manifesting a positive association between the intrinsic frame of reference and validity (veridicality) of description and a negative association between the use of the alternative relative frame of reference and validity of description. The lists in the Relative bias condition were constructed with the same ratio but in the opposite direction so as to induce a positive bias towards the relative frame in terms of validity of description and a negative bias against the intrinsic frame of reference. All in all, each list contained an equal number of valid and invalid descriptions but the valid-invalid ratio for individual frames of reference varied across conditions.

Procedure

Participants saw the stimuli one at a time in a slide show on a laptop screen. The experimental session was preceded by a short practice session. Responses were audio-recorded and subsequently transcribed and coded for verification accuracy and frame of reference of the study phase response. After the practice trials, the 32 target trials were presented in the study phase, in a sentence-picture combination each. In the study phase, participants were asked to study the stimuli, read aloud the sentence description offered and verify verbally the validity of the description of the scene as presented in the sentence by saying ‘Yes’ if it was valid and “No” if it was invalid. The study phase was followed by a distractor task where participants counted downwards from the number two-hundred and fifty by subtracting the number seven at each step until they reached one hundred. Following this, during the test phase, participants saw the truncated version of the sentence and the middle object from the original study phase scenes and were asked to indicate verbally and by pointing the position of the locatum with respect to the reference object as they recalled it from the study phase.

Results

Out of the twenty-eight participants, the data of one was not included in the analyses as this participant’s statement verification accuracy was at chance level (53% accuracy). It was possible that she did not understand the task or was confused for other reasons. Numbers of remaining participants were equally distributed across the three bias conditions, $n = 9$ in each.

The data of the remaining twenty-seven participants were examined in repeated measures analyses of variance with Bias condition as a between-participant variable and Prime (intrinsic vs. relative FoR), and veridicality (True vs. False statement) as within-participant independent variables. Across analyses, veridicality did not exhibit any main effects and did not engage in interactions with other factors. Therefore, the data were collapsed to allow for the analyses of effects and interactions of the two main experimental variables, i.e., Bias condition and Prime FoR. The results of these analyses are reported here on mean participant values.

First, the statement verification responses of participants were subjected to a repeated measures analysis of variance with prime (intrinsic vs. relative) as a within-participant variable and bias condition (neutral, intrinsic bias, and relative bias) as a between-participant variable. Verification accuracy ranged from 88.88% for the neutral condition after a relative prime to 96.53% for the relative bias condition after an intrinsic prime. However, there were no reliable effects and no interactions emerged from this analysis.

Next, a repeated measures analysis of variance with prime (intrinsic vs. relative) as a within-participant variable and bias condition (neutral, intrinsic bias, and relative bias) as a between-participant variable was conducted for the main dependent variable in the memory part of the study – the mean percent choice of intrinsic placement of the locatum with respect to the relatum. As a reminder here, the orientation of the central object in the visual scenes was reversed from study to test phase. For example, if participants saw the goat in Fig. 1b facing to the right during the study phase, in the test phase they saw the goat facing left and were asked to indicate where the locatum (here, the balloon) was positioned in the scene they saw during the study phase. If participants indicated that the balloon was left of or in front of the goat, this was coded as an intrinsic response, as it retained the intrinsic FoR relationship between locatum and relatum while violating the relative (viewing position) FoR of the participant. Alternatively, if participants indicated that the balloon was to the right of or behind the goat, this response was coded as retaining the relative FoR and it was in violation of the intrinsic FoR for the original scene. On this basis, a unitary dependent variable was calculated which reflected the proportion of Intrinsic FoR placement responses out of all responses made by participants. The memory test phase responses were included in the analyses only for those trials on which a correct verification response had been produced in the first study phase of the experiment (excluding seventy-three individual trials across all participants).

The repeated measures analysis on the mean percent of intrinsic placement responses revealed no effect of Bias condition, a significant main effect of prime FoR, ($F_{(1, 24)}$ = 16.99, $p < .001$, η_{p2} = .415) and a significant prime FoR by Bias condition interaction, ($F_{(1, 24)}$ = 5.87, p = .008, η_{p2} = .328). The mean percent values for each of the six conditions are listed in Table 1 below.

Table 1: Mean percent intrinsic placement in the test phase as a function of Bias Condition and Prime (FoR).

Bias Condition	Intrinsic Prime	Relative Prime
Neutral baseline (no bias)	51.77	36.90
Intrinsic FoR Bias	54.81	31.86
Relative FoR Bias	39.58	40.92

Further, we analyzed whether participants' placement responses differed for each of the three experimental bias conditions on the proportion intrinsic placements as a function of the frame of reference the prime was in (intrinsic *in front of* or *behind* vs. relative *left* or *right*). A series of paired samples t-tests were performed with prime FoR as a within-participant independent variable and mean percent intrinsic placement during the test phase as the dependent variable. These analyses revealed that there were significant differences in placement between intrinsic and relative prime trials in the neutral no-bias condition ($t_{(8)}$ = 2.80, p = .023) and in the intrinsic bias condition ($t_{(8)}$ = 4.65, p = .002) but none in the relative bias condition.

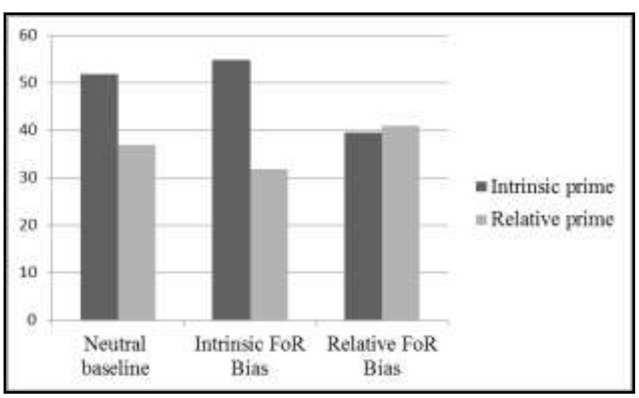


Figure 3: Mean percent *intrinsic* placement after intrinsic or relative FoR primes in each of the three bias conditions.

Discussion

One of the main objectives of this study was to establish if prior descriptions of spatial relations in visual scenes via specific spatial frames of reference could affect the memory for these relations in a test phase. The findings reveal that this was indeed the case. Overall during recall, participants chose placements in the intrinsic object-centered frame more frequently if they had read and verified a description of the relationship in that frame when studying the visual scenes than if they had read and verified descriptions in the alternative relative frame of reference. The priming effect was to the magnitude of a 15% difference between intrinsic prime trials and relative prime trials in the neutral no-bias condition where the two frames of reference were associated equally with success or failure. Thus, importantly, the priming effect of prior verbal FoR description was found in the baseline condition and may generalize to a broader range of phenomena.

Furthermore, in this design differences among the frames of reference were introduced in terms of the degree of their association with veridicality of description, or in other words, on the validity and reliability of descriptions in the intrinsic and in the relative frames, respectively, resulting in two conditions with a bias. The hypothesized interaction between condition bias and frame of reference prime on subsequent spatial memory choices was confirmed in the analysis of data. The spatial description priming effect was shown to differ across bias conditions. The fifteen percent difference in the baseline was increased to a 23% priming magnitude in the Intrinsic bias condition in line with expectations that the intrinsic FoR would be experienced as more reliable in that condition than the relative FoR. The opposite was the case in the relative bias condition—the priming effect dissipated and participants' memory was unaffected by the verbal prime's frame of reference. If we consider that choices in the baseline (default) no-bias condition were under the influence of the prime, these results indicate that the intrinsic FoR was inhibited in the relative bias condition while it was not, or even, as a whole, it was boosted in the intrinsic bias condition. These differences across conditions reveal that participants were sensitive to the level of reliability of the two frames of reference used in the descriptions even though they were not explicit in any way, and the distribution of validity varied across the two frames only implicitly in terms of the overall composition of 'yes' and 'no' (valid and invalid description) trials during the verification/study phase of the experiment. Participants were able to acquire this kind of statistical information during study inadvertently, a form of statistical learning (Saffran, Aslin, & Newport, 1996).

The third hypothesis that veridicality (validity) of the description in interaction with primes would also lead to differences in placement choices was not confirmed in this analysis. If it had any influence at all, it must have been too subtle to make an impact on participants' behavior, especially in view of the combined influence of prime frame of reference and bias condition. The role of veridicality of specific descriptions, however, was not lost entirely, as it was manifested indirectly in the differences across bias conditions with their variation in terms of FoR reliability. In this sense, its role emerged not locally at the level of individual trial descriptions but globally at the level of entire frames of reference being more or less trustworthy as successful descriptive choices.

Conclusion

In sum, this study examined the role of spatial frames of reference used with different degrees of reliability in the description of spatial relations between two objects in memory. The effect of spatial frame of reference priming we found shows that alternative verbal descriptions can produce rather different memories of the same simple visual scene.

Studies of spatial memory have shown inter-cultural and intra-cultural variability in the use of spatial frames of reference and associated performance in non-linguistic tasks. To the best of our knowledge, however, previous research has not examined directly the effects of verbalization of spatial relations via specific FoR terms on subsequent memory for the relations. Whether such effects can be established is, however, a pertinent question for several reasons. One clear avenue of research is the possible role of language for performance in non-linguistic tasks, and in particular, in memory. While such tasks can occasionally be executed without recourse to language, verbal strategies may facilitate memory performance. Future research may explore whether prior descriptions with spatial frames of reference can affect memories where recall is not required, i.e., in recognition tasks. The lack of verbalization in the test phase in such recognition memory tasks may reduce the effects of FoRs. However, if priming occurs in recognition tests as well, then verbal descriptions can be seen as priming frames of reference on a conceptual rather than verbal level.

Importantly, the findings here provide direct evidence that spatial frames of reference can influence spatial memory and that this influence depends on how frequently a frame of reference is associated with valid and reliable information. This finding has a much more general relevance for understanding cognitive mechanisms, for example, if a given conceptual scheme or structure becomes associated with less reliability as an information source, it may also be less favored in subsequent cognitive processes.

Reliability of descriptive schema is indeed a promising characteristic to explore in future research. It is remarkable that participants in the study appeared to be sensitive to the probabilities of validity associated with the different frames of reference even within the limited duration of the experiment and the limited number of instances that were required to produce a bias of expectation towards a given more reliable frame of reference. To what extent such induced variation in reliability can be examined with respect to more ecologically valid field studies is a matter of future research endeavor.

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