Spatial Language and Reference Frame Assignment; The Role of the Located Object

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Abstract

Spatial prepositions work as pointers to localize objects in space. For instance "The book is over the table" indicates that the located object (LO) is somewhere "over" the reference object (RO). To understand where the LO is people need to assign direction to space (selecting a reference frame). Three experiments are reported which investigated the reference frame conflict between LO and RO. We found that when the LO was not vertically aligned, the appropriateness for a given spatial preposition (*above, below, over* and *under*) changes. In general scenes with the LO pointing at the RO were judged less acceptable than scenes with the LO vertically oriented. These results suggest that reference frames for both LO and RO are accessed before direction can be assigned for spatial prepositions. Modifications to Multiple Frame Activation theory (Carlson-Radvansky & Irwin, 1994) are discussed.

Introduction

Spatial language forms an essential part of the lexicon for a competent speaker of a language. In English, spatial prepositions work as pointers to localize objects in space. For instance "The book is over the table" indicates that the located object ("the book") is somewhere "over" the reference object ("the table"). Prepositions like "over" and "behind" (the so-called projective prepositions) are particularly interesting as they require the selection of a reference frame before the assignment of a direction to space specified by the preposition can be established. Levinson (1996) distinguishes between the intrinsic (object-centred), relative (or viewer-centred/deictic), or absolute (environment-centred/extrinsic) reference frames. For example, "the car is behind the house" used intrinsically locates the car in relation to the opposite wall from where the salient front of the house is (which is where the back door is). The relative use of the same expression locates the car directly behind the opposite wall to where the speaker and hearer are standing. The absolute frame locates an object with respect to a salient feature of the environment, such as the gravitational plane or cardinal directions (e.g., North, South, etc.).

Carlson-Radvansky and Logan (1997) have argued that spatial apprehension occurs in a series of stages as follows; (1) identify the reference object (e.g., the house), (2) superimpose multiple reference frames (relative and intrinsic), (3) construct spatial templates and align them to the relevant reference frames, (4) select a reference frame, (5) combine templates into a composite template, (6) search the composite template that fits best with the located object for each position within the template, (7) calculate whether the goodness of fit measure for the located object is high (good or acceptable region) or low (bad region). In this paper we focus on the process underlying the orientation of space and the consequent reference frames selection.

Experimental evidence has demonstrated that by rotating the reference object by 90º (noncanonical orientation), acceptability ratings for *above* mirror the new spatial template that is the sum of all the reference frames active in that moment (Carlson-Radvansky & Irwin, 1994). The acceptability for the given spatial preposition varies as a function of the reference frame activated. Consider the scenes in Figure 1. In the canonical orientation the absolute, relative and intrinsic reference frames overlap. In the noncanonical orientation the absolute reference frame is dissociated from the intrinsic. This produces a lower acceptability for the given spatial preposition because a conflict emerges between all the reference frames activated in that moment (Carlson-Radvansky & Irwin, 1994; Carlson, 1999).

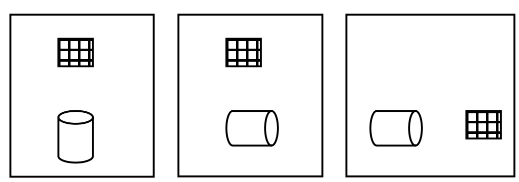

Figure 1: Canonical absolute/intrinsic "above" (left picture), noncanonical absolute "above" (middle picture) and noncanonical intrinsic "above" (right picture).

Although there is evidence that reference frame activation is important, to date studies have only focused on the reference frame generated from the reference object (Carlson & Logan, 2001; Carlson, 1999; Carlson-Radvansky & Logan, 1997). Furthermore, theories of spatial language largely assume that the assignment of direction is generated from the reference object to the located object. For example, in the Attentional Vector-Sum model (Regier & Carlson, 2001) the direction indicated by a spatial relation is defined as a sum over a population of vectors that are weighted by attention. An attentional beam is focused on the reference object (at the point that is vertically aligned with the closest part of the located object) and separated in a population of vectors pointing toward the located object. But other experiments suggest that both objects (even distractors or those not relevant for the task) require allocation of attention to be processed (Lavie, 1995; Lavie & Cox, 1997). This suggests that both objects could play a role in the spatial apprehension process.

There is much evidence indicating that the LO is important in establishing the acceptability of a range of spatial prepositions (see Coventry & Garrod, 2004 for a review). For example, Coventry, Prat-Sala and Richards (2001) found that the appropriateness of a spatial preposition is correlated with the functional relation between located and reference object. For example, an umbrella is regarded as being more *over* a person if it is shown to protect that person from rain than when the rain is shown to hit the person. Furthermore, Coventry et al. found that the acceptability ratings for *over* and *under* were more influenced by the function of the object than by the relative positions of LO and RO, while conversely *above* and *below* were more influenced by geometry than function. Additionally, in a study which manipulated reference frame conflicts with function present (e.g., the man holding the umbrella in the gravitational plane was either upright, lying down, or upside down), Coventry et al. found that reference frame conflicts influenced the acceptability of *above* and *below* more than *over* and *under*.

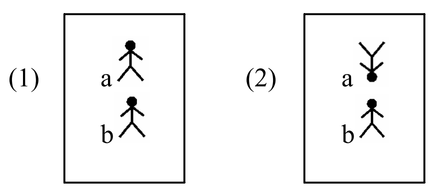

Figure 2: Reference frame conflicts between LO and RO.

However, although there is much evidence that the located object does influence the acceptability of a range of prepositions, no studies to date have examined whether the located object contributes to reference frame assignment, and hence the assignment of direction to space. This paper reports three experiments employing an acceptability rating task where possible reference frame conflicts for both the located object and reference object are manipulated. For example, consider the scene in Figure 2, and the acceptability of man [a] is above man [b]. In (1), the reference frame of man in location [a] is aligned with the reference frame of man [b] (the reference object), but not in (2) where their intrinsic reference frames are in conflict. We predicted that rotating the LO in this way would influence the appropriateness of *over, under, above* and *below*

Experiment 1

In this experiment we tested the hypothesis that the reference frame(s) associated with the located object would affect acceptability of *over, under, above* and *below* to describe the position of the LO in relation to a RO.

Method

Participants & Procedure

Twenty-three undergraduate students from the University of Plymouth participated in this investigation for course credit. All the participants were English native speakers. Participants had to judge the appropriateness of a spatial preposition (*above, below, over* or *under*) to describe pictures using a scale from 1 to 9 (where 1 = not at all acceptable and 9 = perfectly acceptable). All trials showed the located object in a “good” or “acceptable” location, never in a “bad” location (following Carlson-Radvansky and Logan’s definitions, 1997).

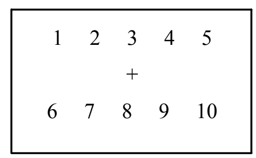

Figure 3: Location for the located object with respect to the reference object (indicated here with a “plus”).

The located object could appear in 10 different locations around the reference object (see Figure 3). The sentences were shown before the scene and in this form; <The “located object” is PREPOSITION the “reference object”>. The prepositions tested were *above, below, under* or *over*. Two orientations for the located object were used: “vertical” and “pointing at”. In the “pointing at” condition the axis of the located object was pointing exactly towards the center-of-mass of the reference object.

Materials

The materials consisted of three stimuli; a circle, an hourglass and a stickman. These objects were selected as the circle does not have an oriented axis, while the hourglass has a salient axis but not an intrinsic top and bottom, and the stickman has a salient axis and an intrinsic top and bottom. We will use the following labels to classify the objects; “no axis” (circle), “ambiguous axis” (hourglass) and “intrinsic axis” (stickman). All the objects employed were presented at the same size and distance from the reference object regardless of the orientation. This is because it has been found that proximity, center-of-mass orientation and distance affect the appropriateness of spatial preposition (Regier & Carlson, 2001).The objects could appear as reference objects or as located objects, but the same object was never shown as LO and RO at the same time.

Design

The experiment consisted of 480 trials constructed from the following variables: 4 spatial prepositions X 10 locations X 3 objects X 2 orientations ("vertical" and "pointing at"). The locations were collapsed in two factors; high vs. low location (2 levels) and proximity (3 levels) as follows; far misaligned (locations 1, 6 and 5, 10) versus near misaligned (locations 2 and 4) versus aligned (central location). All the trials were presented in a randomized order.

Results

A 4-way within subjects ANOVA was performed on the rating data. The variables included in the analysis were; 2 located objects (hourglass versus stickman) x 2 preposition set (above-below vs. over-under) x 2 superior versus inferior prepositions (above-over vs. below- under) x 2 orientations of LO (vertical and pointing at). The division between spatial prepositions has been employed following the Coventry et al. findings summarized above (Coventry, Prat-Sala and Richards, 2001).

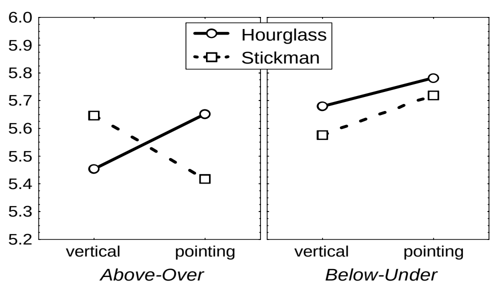

Figure 4: 3-way interaction between superior versus inferior prepositions (above/below vs. over/under), located object and orientation of LO (collapsed over locations).

Trials with the circle as the located object were excluded from the analysis since this kind of object does not have an axis. Furthermore we analyzed only the trials with a circle as the reference object because it has no axis. A main effect of preposition set (above-below vs. over-under) was found, [$F_{(1,\ 22)} = 7.21$, $p < .05$]. Higher ratings were given for Above-Below (M = 6.526) than for Over-Under (M = 5.192). This is unsurprising as it known that these spatial prepositions have larger areas of acceptability. No other significant main effects were found. There was a significant 3-way interaction between superior versus inferior spatial prepositions, located object and orientation of LO [$F_{(1,\ 22)} = 6.694$, $p < .05$], displayed in Figure 4. It is interesting to note that objects with a top/bottom orientation such as a stickman are rated less acceptable when pointing (M = 5.42) than when vertical (M = 5.65) for trials with above-over, although this was not the case for below-under ($M_{vertical} = 5.58$; $M_{pointing} = 5.72$). None of the other interactions were significant.

Discussion

An interesting difference was found between trials with the stickman and trials with the hourglass as LOs. The stickman trials generate a reference frame conflict in the pointing condition but the hourglass did not. This could be explained by a preferential assignation of a top/bottom orientation based on the vertical plane. In other words an hourglass could not be seen as upside down but always as pointing away from the reference object.

Acceptability rating showed that for inferior spatial prepositions (below-under) the pointing condition was more acceptable than the vertical one. All these results can be explained by the activation of an intrinsic reference frame on the located object that in the case of under-below produces facilitation and with above-below produces conflict. Therefore the results seem to suggest that the orientation of the located object is important in establishing the appropriateness of projective prepositions. However, this experiment only used two located objects (an hourglass and a stickman), so there is an issue regarding the extent to which the results can be generalized. For this reason the aim of the next experiment is to try to replicate the effect of the orientation of the LO using a wider range of LOs and orientations of LO.

Experiment 2

The second experiment utilized the same design and procedure as the first experiment, except that more materials and orientations of LO were included.

Method

Participants & Procedure

Twenty-nine undergraduate students from the University of Plymouth participated in this investigation for course credit. All the participants were English native speakers and none of them took part in the previous experiment. The procedure was the same procedure used for the previous experiment based on the acceptability rating task of the given spatial prepositions; *above, below, over* and *under*.

Materials

This experiment involved a wider number of located objects and two more orientations; "pointing away" from the reference object and "upside down". The reference object in this experiment was always a picture of a football. The located objects were picked from two sets; the first consisted of objects with a distinctive top-bottom (8 new objects "with an intrinsic axis") and the second one of objects with "an ambiguous axis" (7 new objects plus the hourglass). All the stimuli were hand-drawn and transformed to electronic format by a computer scanner.

Design

There were 384 trials constructed from the following variables: 8 located objects X 3 locations (collapsed over side) X 4 spatial preposition X 4 orientations ("vertical", "upside down", "pointing at" and "pointing away"). All the trials were presented in a randomized order. We added 192 distractors where the LOs were objects without salient axes, meaning that a total of 576 trials were presented.

Results

A full factorial ANOVA was chosen to analyze the data. In this analysis we focus on trials where the LO had an intrinsic axis (following the results of Experiment 1). A significant main effect was found for preposition type (above-below vs. over-under), [$F_{(1,28)} = 15.44$, $p < .001$], for superior versus inferior prepositions, [$F_{(1,28)} = 10.72$, $p < .005$], for location [$F_{(1,28)} = 80.17$ $p <.0001$] and for direction [$F_{(1,84)} = 3.35$, $p < .05$]. Objects vertically oriented (M = 5.75) were judged more acceptable than the other levels of orientation. In particular the "upside down" (M = 5.6) and "pointing at" (M = 5.55) orientations produced the lowest ratings (and indeed generated the highest reference frame conflict). The analysis also revealed significant 2-way interactions between preposition set and location [$F_{(1,28)} = 10.96$, $p < .005$], between preposition set and direction [$F_{(1,84)} = 3.23$. $p < .05$] and between superior versus inferior prepositions and direction [$F_{(1,84)} = 2.82$, $p < .05$].

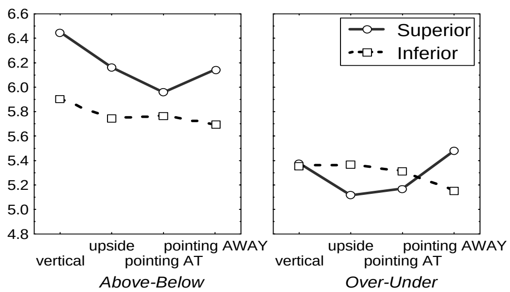

Figure 5. 3-way interaction between orientation of LO, superior-inferior prepositions and preposition set.

Finally, there was also a significant 3-way interaction between superior-inferior prepositions, preposition set and location, [$F_{(1,28)} = 5.45$, $p < .05$], and between preposition set, superior-inferior preposition and direction [$F_{(1,84)} = 3.99$, $p < .01$]. This interaction is displayed in Figure 5. As can be seen in Figure 5, the results of the orientation of LO are clearest for *above*, which exhibited a reliable difference between the vertical orientation of LO and all the other levels of LO. For *over*, pointing away from the RO is also associated with higher acceptability ratings. The results are less clear for inferior prepositions.

Discussion

The pattern of results in this second experiment confirms the hypothesis that the orientation of the located object influences acceptability ratings, although there are clear differences between prepositions. However, in the first two experiments the reference objects were objects without a salient axis. It is therefore possible that the activation of the located object reference frame could depend on the features of the reference object. The next experiment tested whether the effects of the orientation of LO were present across a wider range of ROs.

Experiment 3

This experiment used the same basic methodology as before, but this time with a range of reference objects including ROs without a salient axis, with an ambiguous axis, and with an intrinsic axis.

Method

Participants& procedure

Twenty-three undergraduate students from the University of Plymouth participated in this investigation for course credit. All the participants were English native speakers and they did not take part in any of the previous experiments. The procedure was the same as that used in Experiments 1 and 2.

Materials

For this experiment we used a set of 24 objects (8 "without a salient axis", 8 "with an ambiguous axis" and 8 "with an intrinsic axis"). The objects "with an ambiguous axis" and "with an intrinsic axis" were the same as those used in Experiment 2. We drew 8 new objects "without a salient axis". Thus we were able to study the effect of the reference frame activation on the located object in scenes with different kinds of reference object.

Design

The experiment was composed of 576 trials with the following factors: 8 located objects with an intrinsic axis (treated as random factor), X 3 reference objects (picked up from a set of 24 objects, 8 with no axis, 8 with an ambiguous axis, and 8 with an intrinsic axis; within subjects factor), X 2 prepositions set (between subjects factor), X 2 superior-inferior preposition (within subjects), X 3 locations for the probe (within subjects) and 4 directions for the located object (within subjects). This time preposition set was between subjects; half the participants received *above* and *below* and the other half received *over* and *under*.

Results

We performed two analyses; one by subjects (F^1) and one by materials (F^2). The results were similar for both analyses, so here we report the F^1 analyses alone. The means for all the conditions can be found in Table 1. Significant main effects were found for superior-inferior prepositions [$F_{(1,22)} = 18.74$, $p < .001$], for location [$F_{(1,22)} = 69.14$, $p < .0001$] and for orientation of LO [$F_{(1,44)} = 5.25$, $p < .005$]. Furthermore we found several significant 2-way interactions; between preposition set and RO [$F_{(1,44)} = 3.61$, $p < .05$], between location and RO [$F_{(1,44)} = 4.45$, $p < .05$], between superior-inferior prepositions and orientation of LO [$F_{(1,66)} = 4.93$, $p < .005$] and between location and orientation of LO [$F_{(1,66)} = 3.12$, $p < .05$].

Located Object (intrinsic)		Reference Object		
		No axis	Ambig.	Intrin.
Above	vertical	6.281	6.307	6.375
	inverted	5.560	5.542	5.490
	point at	5.524	5.670	5.644
	point away	6.047	6.026	5.974
Below	vertical	5.797	6.036	6.167
	inverted	5.411	5.604	5.453
	point at	5.786	5.823	5.754
	point away	5.387	5.536	5.578
Over	vertical	5.419	5.084	5.479
	inverted	5.047	4.823	5.220
	point at	5.182	5.115	5.188
	point away	5.785	5.366	5.335
Under	vertical	5.131	5.058	5.162
	inverted	4.691	4.901	4.889
	point at	5.335	5.073	5.156
	point away	4.698	4.693	4.901

Table 1. Means for conditions across the four spatial prepositions (*above, below, over and under*).

A 3-way interaction was also significant between superior-inferior prepositions, location and orientation of LO [$F_{(1,66)} = 3.93$, $p < .05$] and a 4-way interaction between superior-inferior prepositions, location, RO and orientation of LO [$F_{(1,132)} = 2.74$, $p < .05$]. Follow-up analysis revealed significant differences in orientation between prepositions and locations, but the effects of orientation were present at all levels of RO.

Discussion

The outcome from this experiment supports the idea that the orientation of the located object affects acceptability ratings even when the reference object has an intrinsic orientation. The results for this experiment mirror the results of the previous experiment, but extend the results to show that the activation of reference frame for the LO is not restricted to cases where the RO does not provide sufficient information to cue a reference frame.

General Discussion

The series of experiments explored the hypothesis that the spatial apprehension process computes a composite template for a given spatial preposition making use of the located object reference frame as well as the reference object reference frame. The results of the experiments confirmed this hypothesis showing that the orientation of the located object affects acceptability ratings for projective prepositions.

The results suggest necessary extensions to the idea of Multiple Frame Activation (Carlson-Radvansky & Irwin, 1994) where it is suggested that in comprehending a scene multiple frames are available. However, we found that an additional reference frame is generated from the located object as well as from the reference object and the final template generated is influenced by its orientation.

In addition to the reliable effects of the orientation of LO for intrinsic objects, the results of Experiment 1 showed some interesting differences between intrinsic objects and objects such as an hourglass with a salient axis, but without an intrinsic axis. For the objects like an hourglass, the "pointing at" condition was considered more acceptable than the vertical condition. A possible explanation is that people assign a subjective top/bottom orientation to "ambiguous" objects. Thus the hourglass in trials with above-over should be seen as pointing away from the reference object instead of pointing at the RO.

The last experiment provided evidence that the conflict among reference frames emerges across a range of reference objects, including those that are more "real" with a top/bottom orientation. So the effect of the located object is not exclusive for circle-like reference objects but it is part of a more general process.

But why should we activate the located object reference frame when the reference frame of the RO should be sufficient to localize the objects in the scene? An explanation is that objects not vertically oriented suggest that there is something implausible in the scene. A cat upside down is not a "plausible" stereotypical mental representation. Thus the knowledge revision function (Holland, Holyoak, Nisbett & Thagard, 1986, Wason, 1960) should look for an explanation; this activates the located object reference frame to process every possible orientation that fits with the whole scene. Another possible explanation is based on the concept of direction of potential motion (Regier, 1996). People perceive objects rotated away from the gravitational plane as falling. So a located object oriented at 90º may be perceived as moving downwards on a path to the left of/right of and away from the reference object.

Implication for existing models

The results found suggest a review of the key characteristics of the spatial apprehension process Carlson-Radvansky & Irwin, 1994; Carlson & Logan, 2001; Hayward & Tarr, 1995; Logan & Sadler, 1996). We found evidence of an involvement of the located object reference frame in the process of assigning direction to space. Therefore evaluating the process of goodness of fit of the spatial preposition involves the located object as well and future studies should take this into account. The finding that the located object interacts with the spatial apprehension process has some repercussions for models of spatial language as well. Models such as the Attentional-Vector-Sum model (Regier & Carlson, 2001) simulate attentional processes, but thus far does not deal with attentional processing of the LO (but see Regier, Carlson & Corrigan, 2004, for a modification of AVS to deal with processing of function). It may be possible to develop the AVS model to deal with the projection of vectors from the LO to the RO as well as the other way round (see Coventry and Garrod, 2004, for a discussion).

Limitations and future developments

This investigation brings experimental evidence in support of the hypothesis that the located object, in a scene with two objects, takes part in the spatial apprehension process. Future investigations should attempt to ascertain the degree to which features of the LO influence the spatial apprehension process further. For example, in some contexts the LO may be more important than the RO, and vice versa for other contexts. In addition, the present experiments do not tell us anything about the time course of processing of LO reference frames. Studies underway are testing the conflict among reference frames using a reaction time paradigm. Finally, we should consider how these findings can be implemented within frameworks such as the AVS model.

Acknowledgments

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References

Carlson-Radvansky, L. A. & Irwin, D. E. (1994). Reference frame activation during spatial term assignment. *Journal of Memory and Language*, 33, 646 – 671.

Carlson-Radvansky, L. A. & Logan, G. D. (1997). The influence of reference frame selection on spatial template construction. *Journal of Memory and Language*, 37, 411 – 437.

Carlson, L. A. (1999). Selecting a reference frame. *Spatial Cognition and Computation*, 1, 365 – 379.

Carlson, L. A. & Logan, G. D. (2001). Using spatial terms to select an object. *Memory and Cognition*, 29 (6), 883 – 892.

Coventry, K. R., Prat-Sala, M. and Richards, L. (2001). The interplay between geometry and function in the comprehension of Over, Under, Above and Below. *Journal of Memory and Language. 44(3),* 376 – 398.

Coventry, K. R., & Garrod, S. C. (2004). *Saying, seeing and acting. The psychological semantics of spatial prepositions.* Psychology Press; Hove and New York.

Hayward, W. G. & Tarr, M. J. (1995). Spatial language and spatial representation. *Cognition*, 55, 39 – 84.

Holland, J. H. , Holyoak, K. J., Nisbett, R. E. & Thagard, P. R. (1986). *Induction: Processes of inference, learning, and discovery*. Cambridge, MA: MIT press.

Lavie, N. (1995). Perceptual load as necessary condition for selective attention. *Journal of Epxerimental Psychology: Human, Perception and Performance*. 21(3), 451 – 468.

Lavie, N. & Cox, S. (1997). On the efficiency of visual attention: efficient visual search leads to inefficient distractor rejection. *Psychological Science*. 8(5), 395 - 398

Levinson, S. C. (1996). Frames of reference and Molyneux's question. In P. Bloom, M. A. Peterson, L. Nadel, & M. F. Garrett (Eds.), *Language and space* (pp. 109-169). Cambridge, MA: MIT Press.

Logan, G. D. & Sadler, D. D. (1996). A computational analysis of the apprehension of spatial relations. In P. Bloom, M. A. Peterson, L. Nadel, & M. F. Garrett (Eds.), *Language and space* (pp. 493-529). Cambridge, MA: MIT Press.

Regier, T (1996). *The Human Semantic Potential. Spatial language and constrained connectionism*. Cambridge, The MIT Press.

Regier, T. & Carlson, L. A. (2001). Grounding spatial language in perception: An empirical and computational investigation. *Journal of Experimental Psychology: General*, 130 (2), 273 – 298.

Regier, T., Carlson, L. A., & Corrigan, B. (2004). *Attention in spatial language: Bridging geometry and function*. In L. Carlson & E. van der Zee (Eds.). Functional features in language and space: Insights from perception, categorization and development. Oxford University Press.

Wason, P. C. (1960). On the failure to eliminate hypothesis in conceptual task. *Quarterly Journal of Experimental Psychology*, 12, 129 – 140.