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Function, geometry and spatial prepositions: Three experiments

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Abstract. In this paper the results of three experiments are reported which address the issue of the relative extent to which functional relations versus geometric relations affect spatial language. The experiments examine the role of a discourse context on the use and rating of the preposition *in* to describe a visual scene where the constraint of spatial containment between figure (object located) and ground (reference object) does not hold. All three experiments demonstrate that *in* is used more and rated to be significantly more appropriate in a functional context than in a no context condition. The implications of these studies for spatial language and spatial representation are discussed.

Key words: function, geometry, *in*, spatial prepositions

While most approaches to the meaning of spatial prepositions have assumed that spatial prepositions refer to regions of space, recently the role of geometry as a sole determinant of the use and comprehension of spatial language has been called into question (see Coventry 1998 for a review; Garrod and Sanford 1989; Vandeloise 1994). A number of studies demonstrate that the use and comprehension of spatial prepositions is underdetermined by geometric relations, and is affected by a range of extra-geometric relations. These extra-geometric relations encompass a range of variables to do with the functions of objects, and whether objects are able to fulfil their functions in context. Coventry (1998) reports effects of movement of figure (object to be located) and ground (reference object) on the use and acceptability rating of *in* while geometric relations remain constant. For example, contiguity of movement of figure with ground was found to significantly increase the use and rating of *in* when a figure was positioned on top of a pile of objects high above the rim of a bowl. Similarly, movement of the figure independently of the ground was found to reduce the use and rating of *in* with high piles. Coventry, Carmichael and Garrod (1994) have also shown that these kinds of effects may well be object specific. For example, they report differences in the use and rating of *in* to describe a figure (a solid) in a

bowl versus a jug which are compatible with the view that jugs are regarded as containers of liquids while bowls usually contain solids.

Information that a figure is fulfilling its function has been found to affect the use and ratings of other prepositions aside from *in*. Coventry and Prat-Sala (1998) have found that the ratings of *over*, *under*, *above*, and *below* were influenced by whether an object with a particular function (e.g., an umbrella) was depicted as fulfilling its function or not (e.g., rain falling on an umbrella protecting the person holding the umbrella getting wet versus rain falling on the person missing the umbrella). Coventry and Mather (in press) also report a relationship between the preposition *over* and knowledge of how objects fall to the ground (Newton's laws). Furthermore, Carlson-Radvansky and Radvansky (1996) have also found that functional relations influence the choice of frame of reference for projective prepositions.

While the importance of extra-geometric relations on the use and comprehension of a range of spatial prepositions has been established, there are two central issues that need to be tackled. Firstly, and the main focus of the present paper, is the issue of the extent to which extra-geometric and geometric factors contribute to a model of use and comprehension. Different views exist as to how to deal with the types of effects reviewed above. Coventry (1998) and Garrod and Sanford (1989) argue that the effects should be tracked back to the lexicon so that the lexical entry for *in* is something like:

> *In*: functional containment – *in* is appropriate if the ground is conceived of as fulfilling its containment function.

This implicates a number of factors which influence appropriateness aside from geometric relations. These factors are not added onto the geometry in this account, but are an important part of the essence of *in* from the outset. Certain types of geometric relations afford functional containment. An object touching the bottom of a container is spatially and functionally contained. In this respect geometry serves to provide evidence about the likelihood that the figure will stay in the same relative position to the ground over time, and whether the ground is able to fulfil its function. This approach does not deny the importance of geometry, but rather regards geometric and extra-geometric variables as equally important variables which are likely to be instantiated in the early stages of use and comprehension.

Landau and Munnich (1998) have suggested an alternative interpretation of the empirical findings outlined above. While recognising that extra-geometric variables are important, they argue that these kinds of effects are essentially added onto the geometry to modify the geometric regions appropriate. Furthermore, Landau and Munnich argue that these geometric regions are well specified. This view would appear to be in line with that of Herskovits (1986), who has outlined a set of pragmatic principles (termed

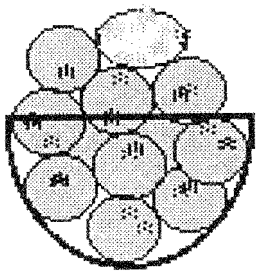

Figure 1.

near principles) which bend and stretch the geometric constraints embodied in the lexicon under some circumstances. For example, Herskovits has argued that *in* is appropriate in Figure 1 to describe the location of the *lemon* in relation to the *bowl* as a result of the principle of *tolerance* which allows *in* to be appropriate as the figure is part of a group of other objects, some of which meet the containment condition. In this way a pragmatic principle allows an extension of the geometric containment region applicable.

Function and geometry may be so inextricably linked that testing which of these explanations is correct may be difficult. However, one way of getting at this issue is to examine cases where either functional constraints or geometric constraints do not hold, and find out whether a term is or is not appropriate in such cases. Even with less central senses of *in*, the geometric constraint of containment still must apply for *in* to be appropriate. In the case of tolerance, the geometric constraint does hold by virtue of the figure being regarded as part of a whole pile, thus part containment is present. Clearly therefore a test case for these theories is one where the geometric constraint does not hold directly (or indirectly by virtue of the application of a pragmatic principle for that matter), but where a functional constraint does hold. Garrod and Sanford (1989) provide a convenient example of functional control of this type. Ordinarily one would not say that *the pear is in the bowl* to describe the relationship between figure and ground in Figure 2. However, if one was playing a game which involved manipulation of the frame such that one had to place the pear within the circumference of the bowl then one could meaningfully say that the pear is *in* the bowl. Garrod and Sanford (1989) argue that this is because the imposition of the model from the text on the scene allows the functional containment relation to hold as one has to move the pear so that the bowl functionally contains it. The experiments reported below test this claim directly.

The second central issue relating to geometric and extra-geometric factors is the relative extent to which individual spatial terms are affected by these

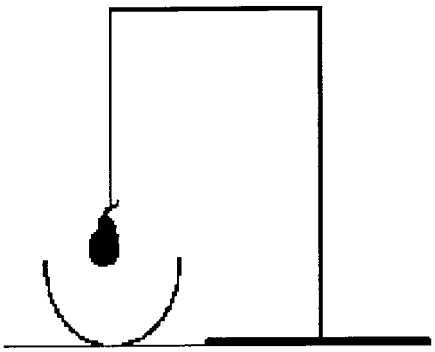

Figure 2.

variables. Evidence is beginning to emerge that suggests that different spatial prepositions may be differentially affected by geometric and extra-geometric relations. While a range of prepositions such as *in* and *over* appear to be very dependent on object knowledge, terms like *above* (which are also acquired later – Sinha et al. 1994) appear to be less contextually constrained and more geometrically based. Although Carlson-Radvansky, Covey and Lattanzi (in press) have shown that *above* can be influenced by functional relations and context, Coventry and Prat-Sala (1998) found, when *over* and *above* were presented together, that *over* was more affected by extra-geometric variables than *above*, while *above* was more affected by geometry than *over*. Indeed they have suggested that spatial prepositions may rest on a continuum from those which are mainly influenced by geometry to those which are mainly influenced by extra-geometric factors. In the present experiments, one can therefore predict that *in* and *over* may be more influenced by the game context than *above* which appears to be less influenced by extra-geometric factors.

Experiment 1

The purpose of the first experiment was to test the use of some prepositions (like *in* and *over*) increase in the game context versus a control context, while the use of other prepositions (like *above*) may decrease.

Design and method

The experiment employed two conditions: a control condition without a prior context and a context condition with a discourse presented above the picture and sentence for completion.

All participants (randomly assigned to conditions) were instructed that they had to complete the sentence 'The pear is ___ the bowl' with a single word. The control condition received the picture alone with the sentence underneath. The experimental group were given the same picture and sentence, but were also given a discourse placed directly above the picture and sentence as follows:

> David and Jane are playing a game. The object of the game is to move the frame such that the pear and bowl are positioned as depicted below. At the end of the game, David (the first to try) shouts, "I have won: the pear is ___ the bowl".

The discourse was constructed without using spatial prepositions which would be likely to prime the preposition *in* (although unavoidably *below* does appear to indicate the position of the scene described in the text).

Participants

243 undergraduate psychology students participated in the experiment for partial course credit. 138 of these were in the context condition and the remaining 105 were in the control (no context) condition.

Procedure

Participants were presented with a cover sheet of instructions asking them to complete the sentence on the following page using a single word such that the sentence correctly describes the picture above it. Participants were instructed to read all the information on the page before completing the task.

Results and discussion

The distribution of response is displayed in Table 1. A Chi-square test revealed a significant effect of context on the distribution of prepositions used to complete the sentence (Chi-square = 10.05, df = 3, $p < 0.05$).

The deviations in expected frequency occurred as a result of an increase in the use of *in* in the context condition, and a proportionate decrease in the use of *above*. No deviations for expected frequency were found with *over*. This result provides evidence for the influence of functional context on the appropriateness of *in*.

Table 1. Distribution of sentence completions in Experiment 1

	Condition	
Completion	Context	Control (no context)
Over	61	47
Above	46	47
In	24	5
Other expression	7	6

Experiment 2

It was decided to repeat Experiment 1 with a shorter string to check that the effect was still present. Some participants in Experiment 1 in the control (no context) condition still produced *in* as the completion although the containment relation does not hold. This could have been a result of their glancing at the scene and thinking that the pear was partially contained by the bowl. This may have also had an effect on the appropriateness of *over*. The use of a shorter length of string bypasses this possible problem.

Design and method

Participants were 222 undergraduate students from the University of Plymouth taking part for partial course credit. 112 of these were in the context condition and the remaining 110 were in the control (no context) condition. The design and procedure was the same as that used in Experiment 1. The only difference was that the length of string from which the pear was suspended was halved, thus the distance between the rim of the bowl and the pear was increased.

Results and discussion

The distribution of response is displayed in Table 2. A Chi-square test revealed a significant effect of context on the distribution of prepositions used to complete the sentence (Chi-square = 21.55, df = 3, $p < 0.05$).

The distribution of completions in this experiment differs from that observed in the previous experiment. Again *in* is the preposition that changed the most with the greatest deviations from expected frequency. This time however the use of *over* also increased in the context condition while the use of *above* decreased.

Table 2. Distribution of sentence completions in Experiment 2

	Condition	
Completion	Context	Control (no context)
Over	35	19
Above	61	89
In	8	0
Other expression	8	2

The results for *in* and *over* support those observed in the first experiment. This time no participants in the control condition used *in*, indicating that the effect cannot be the result of participants not attending carefully enough to the visual scene. The increase in the use of *over* is not surprising give that the pear in this experiment was positioned high above the rim of the bowl. The decrease in the use of *above* supports the prediction that prepositions are differentially affected by the functional context.

Experiment 3

Design and method

This study was a replication of Experiments one and two using a rating methodology with *in* presented alone. Participants (randomly assigned to conditions) were presented with the sentence '*The pear is in the bowl*' and were asked to rate how appropriate *in* was on a 10-point Lickert scale either in the context or control condition (between subjects). This time two lengths of string were used (between subjects); either the pear was positioned as in Experiment 1 just above the rim of the bowl, or the pear was positioned a distance from the rim but still directly above the bowl (as in Experiment 2).

Participants

Participants were 360 undergraduate students from the University of Plymouth taking part for partial course credit.

Results and discussion

Participants who saw *in* in the discourse context rated it as more appropriate than participants who saw it in the null context [$F(1,356) = 7.8$, $p < 0.01$].

Table 3. Mean ratings for *in* (and *standard deviations*) for conditions in Experiment 3

Condition	
No context/low position	2.50 (*1.64*)
Context/low position	3.27 (*2.68*)
No context/high position	1.83 (*1.60*)
Context/high position	2.56 (*2.27*)

Participants who saw the pear just above the rim of the bowl rated *in* as more appropriate than participants who saw the pear high above the rim [$F(1,356) = 6.63$, $p < 0.05$]. However, participants rated *in* as more appropriate in the discourse context no matter where the pear was located [$F(1,356) = 0.004$, $p > 0.05$]. Means and standard deviations by condition are displayed in Table 3.

The results indicate that *in* was rated as being more appropriate for both lengths of string in the context condition.

General discussion

Taken as a whole, the results across the Experiments support the prediction that the presentation of a functional context increases the use and rating of the spatial prepositions *in* and *over* while a decrease in the use of *above* was also observed. The picture illustrated depicted a pear that is above the rim of the bowl, and is therefore not contained in the space displaced by the bowl. Without the context, *in* was not used very much and is given a low rating. With the introduction of the context there was a significant increase in both the use of the term and the ratings given for the appropriateness of the term. For Experiments 1 and 2, the use of *in* increased in the context while the use of *above* decreased. *Over* was used more in the context condition only when the pear was positioned high above the rim of the bowl.

Although it should be noted that *above* and *over* were still the most popular choices to complete the sentence in the first two experiments, the change in use and rating of *in* still poses problems for a purely geometric account. The possibility that factors other than geometric factors extend the region of appropriateness for *in* world appear to be unlikely. The extended use of a term demands that some part of the original range of meaning of the lexical item remains intact. In the case of the experiments reported, the pear is not contained by the region displaced by the bowl. There is therefore no element for the lexical entry that can be extended if the lexical

entry is purely geometric. With the case in Figure 1, the pragmatic principle Herskovits (1986) invokes has plausibility as there are other objects which do meet the criteria for containment required by the lexical entry. In the case we are concerned with here, there are no other objects present, so the principle cannot apply. In both cases, it is perhaps more parsimonious to argue for the lexical entry of functional containment to account for both types of effects. Tolerance really has to do with the notion that the container in Figure 1 is fulfilling its function as the presence of other objects vis-à-vis the force of gravity allows the container to control the location of the lemon over time. With the discourse where *in* becomes more appropriate one can argue that the function of the container is being met in the context in which the expression occurs.

Although the normal containment relation provided by the bowl is not met in this case, the context does indicate a geometric region that would be appropriate in this context. The region is not an extension of the containment relation associated with the normal containment function of the container, but instead is a region that is defined by the context. In this case the region is the area enclosed by the circumference of the rim of the container, and not the area displaced by the container. These results are consistent with the results of Coventry and Prat-Sala (1998). In a functional context, one can say *the umbrella is above the man* (if rain is falling on the umbrella protecting the man from the rain), even if the umbrella is positioned at an angle which would not ordinarily be described as higher than the man. The results therefore suggest that extra-geometric factors do not extend well-defined geometric regions, but rather may set up regions of applicability which become important in a given context.

The results also bring into focus the influence of context on the situation specific meaning of spatial expressions. Most studies in the field have examined the relationship between sentences and visual scenes, usually without a wider context. The extent to which context is the main determinant of situation specific meaning has yet to be established in this domain, but is likely that context can override the contribution of individual lexical items, as has been found to be the case for other word types (see for example, Barton and Sanford 1993). In addition, the shared goals of the communicators involved in dialogue are important to establish situation specific meaning (see Clark and Carlson 1981). While a discourse context is one type of context, real dialogue situations are likely to involve further complexities, such as flexibility in interpretation and sensitivity to the understanding/misunderstanding of the other speakers (see Schober 1998).

Further research needs to be done in order to further address the issue of the relative extent to which the use and comprehension of spatial terms is

determined by functional relations versus geometric relations. This preliminary work, however, suggests that extra-geometric variables may be central to the use and comprehension of spatial prepositions rather than merely added on top of geometric constraints.

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