Geometry, Function, and the Comprehension of *Over, Under, Above* and *Below*

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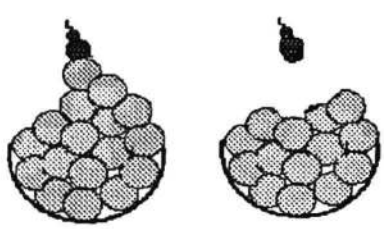
Abstract

One large experiment is reported which examined the role of geometry and functional relations on the comprehension of the spatial prepositions *over, under, above* and *below*. The task consisted of rating how appropriate a sentence (containing one of these prepositions) was to describe a picture. The results show a significant effect of functional relations on the ratings given, demonstrating the importance of functional relations as a determinant of the comprehension of spatial prepositions. However, while *over* and *under* were very sensitive to functional relations, *above* and *below* were more influenced by geometric relations. Thus these results indicate for the first time that spatial prepositions are differentially influenced by geometric and functional relations, and that geometry and functional relations are distinct factors.

Introduction

Spatial prepositions are among the shortest words in the English language. Nevertheless, it is difficult to specify the conditions under which terms like *in* and *over* are used. Traditionally geometric constructs have been invoked to underpin their lexical entries (e.g., Herskovits, 1986). For example, in the sentence, "The pear is in the bowl," the figure (*the pear*) is located in the region described by the prepositional phrase *in the bowl*, with the spatial relation expressed by *in* corresponding to "contained interior to the reference object." However, there is not a direct mapping between spatial relations and prepositional usage. For instance, *in* is appropriate to describe the relationship between the pear and the bowl in 1(a) but *over* would be the most appropriate term in 1(b) although the geometric relations are identical.



(a) (b)

Figure 1

Recently it has been argued that extra-geometric factors may play an important role in the use and comprehension of spatial prepositions. In particular, *functional relations* have been postulated as the key components underlying the meaning of the spatial prepositions *in, on* and *at* (Coventry, 1992, 1998; Coventry, Carmichael and Garrod, 1994; Garrod and Sanford, 1989; Talmy, 1988; Vandeloise, 1994). Functional relations have to do with how objects interact with each other, and what the functions of objects are. For example, with *in*, Garrod and Sanford (1989) and Coventry (1992, 1998) propose that the lexical entry is;

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

Whether or not *in* is appropriate depends on a number of factors which determine whether the container is fulfilling its function. These include movement over time where the figure remains in the same position relative to the container, or where the container is sealed, thus blocking movement of the figure beyond the rim of the container, allowing constraint of location over time.

Empirical evidence for the importance of this functional analysis has been forthcoming for topological prepositions. For example, Coventry (1992, 1998) found that contiguity of movement of figure with ground significantly increased the use and rating of *in* when the figure was positioned on top of other objects above the rim of a container as compared with static scenes where the geometry was the same. Conversely, movement of the figure independently of the ground was found to reduce the use of *in*. Similarly, tilting the container reduces the use of *in* if it looks like the figure may fall out.

In addition to the effects of movement, Coventry, Carmichael and Garrod (1994) provide preliminary evidence that function effects may be object specific. Comparing static scenes involving a jug and a bowl *in* was used significantly more with the bowl as ground than with the jug as ground when the pile was high. Furthermore, adding liquid to the jug was found to further decrease the use (and ratings) of *in*, but made no difference in the case of the bowl. Thus the addition of water appears to make the object-specific function of the jug (to contain liquids) more salient, further reducing the appropriateness of the container as a container of solids. Additionally, Coventry

et al. (1994) found that labelling the same object a *dish* versus a *plate* influences prepositional usage, indicating that different nouns suggest different object-specific properties.

It would appear that the importance of extra-geometric factors as a determinant of the use and comprehension of topological prepositions has been established. However, it is less clear (a) the relative extent to which function and geometry influence the use and comprehension of spatial terms and (b) whether extra-geometric factors influence the use and comprehension of all spatial prepositions.

The present experiment was designed to evaluate the relative extent to which functional versus geometric relations contribute to the comprehension of the prepositions *over, above, under, below.*

Function, Geometry and *Over, Under, Above, Below*

The role of geometry underpinning the use and comprehension of projective prepositions such as *over, under, above* and *below* has been the subject of both extensive linguistic analysis (e.g., Bennett, 1975; Brugman, 1988; Lakoff, 1987) and recent empirical study (Carlson-Radvansky & Irwin, 1993, 1994; Carlson-Radvansky & Radvansky, 1996; Hayward & Tarr, 1995; Logan and Sadler, 1996). Logan and Sadler (1996) found that the prototypical *above* relationship is at a point higher than *directly above* the reference object. Displacing the figure from the central axis of the reference object was found to reduce the appropriateness of the term. However, these studies involved participants marking points or rating scenes involving abstract geometric shapes rather than real objects with any relations between them.

Carlson-Radvansky and Radvansky (1996) found that the presence of a functional relation between objects to be described was associated with a preference for intrinsic descriptions, whereas the absence of a relationship was associated with a preference for deictic-extrinsic descriptions. Coventry and Mather (in press) also demonstrate context effects based on object knowledge with the spatial preposition *over*. They found that the introduction of a context in which a plane had to drop a bomb in order to hit a building significantly influenced the used and rating of *over* to describe the position of the plane at various points on a path higher than the building as compared to a no-context control condition. Furthermore, there was a relationship between where subjects thought *over* was appropriate and where they thought the bomb should be dropped to successfully hit the target. However, no such effects were found for *above*. From this, Coventry and Mather have argued that *over* is more influenced by extra-geometric factors than *above*, and that prepositions may cluster into functional and non-functional types.

The present experiment therefore manipulated geometry and function independently and together in order to assess the influence of both factors on the comprehension of *over, above, under* and *below*. Following the findings of Coventry & Mather (in press) it was predicted that function effects should be present with the prepositions *over* and *under*, but absent with *above* and *below*. Conversely it was predicted that *above* and *below* would be more affected by changes in geometric relations than *over* and *under*.

Experimental Design

The experiment was designed to test for the differential effects of function and geometry on participants' ratings of the appropriateness of sentences to describe a series of pictures. The variables manipulated included three levels of geometry and three levels of functionality. Either the figure in the picture was positioned canonically above the ground, at an angle of 45° or at an angle of 90° to the ground (see Figure 2). For each level of geometry three levels of functionality were employed. The figure was shown to be either fulfilling its function, not fulfilling its function, or other objects were not present to make the functional relationship relevant (a control). The sentences given to rate were presented in pairs for each picture. Each sentence in a pair was identical except for the preposition. For example, a pair of sentences could be *The man is under the umbrella* and *The man is below the umbrella*. The predictions were that if geometric relations had an effect on the comprehension of these prepositions, the participants would give the highest ratings to a sentence when it described a picture where one of the objects appeared in its canonical position and the lowest ratings when the same sentence described a variant of the picture which contained the same object titled at 90°. We were also predicting that if functional relations had an effect, participants' ratings for a particular sentence would be higher when it described a picture depicting a functional relation between objects, than when the functional relation was not present. Additionally, it was predicted that *over* and *under* would be most sensitive to functional relations while *above* and *below* should be more sensitive to geometric relations.

Method

Participants: Thirty-eight undergraduate students from the University of Plymouth participated in this experiment as an extra credit option in a Psychology course. All participants were native speakers of English.

Materials: The materials for the experiment consisted of a total of 144 pictures and were based on two sets of four types of pictures. Each picture in a set had nine variants (3 levels of geometry and 3 levels of functionality), making a total of 72 pictures. Each picture was printed twice, one with a pair of sentences (e.g. *The man is under/below the umbrella*) and the other with another pair of sentences (e.g. *The umbrella is over/above the man*) to test all four prepositions.

The first set of pictures depicted a man using an object to protect himself from a falling object/objects (e.g., *a man using an umbrella to protect himself from rain).* For each picture there were three levels of geometry of the object used by the man to protect himself (in this case the *umbrella*). Additionally, for each geometric permutation there were three levels of functionality: control, where the

object the man tried to protect himself from was absent (e.g. there was no rain); functional, where the object was present (i.e. the rain was falling on the umbrella keeping the man dry); and non-functional, where the falling object was present but the protecting object did not fulfil its function (i.e. the rain was falling on the man despite the umbrella's presence). See Figure 2 for an example of all nine levels of picture for one set of materials.

Figure 2: Examples from Material Set 1

The second set of pictures depicted two related objects (e.g., *can and a pan)*. One of these objects was always a recipient object. For each picture there were three levels of geometry of the recipient object (in this case the *pan*).There were also three levels of functionality: control, where the falling/pouring object was missing (in this case there were no beans in the can); functional, where the falling/pouring object was present (i.e. there were beans falling into the pan); and non-functional, where the falling/pouring object was present but did not end up in the recipient object (i.e. there were beans missing the pan and dropping onto the floor). See Figure 3 for an example of a picture with all nine levels of function/geometry (and Appendix for a description of the picture materials used).

Procedure: Participants were run in groups of 6-10 people. Each participant received the instructions and a booklet containing the material. The participants were told that each page of the booklet contained a picture and two sentences, and that their task consisted of rating how appropriate each sentence was to describe the picture. They were given a 7-point scale where 1 meant totally inappropriate and 7 totally appropriate. Participants were free to use any number in the scale. The experimental sessions lasted around 30 minutes.

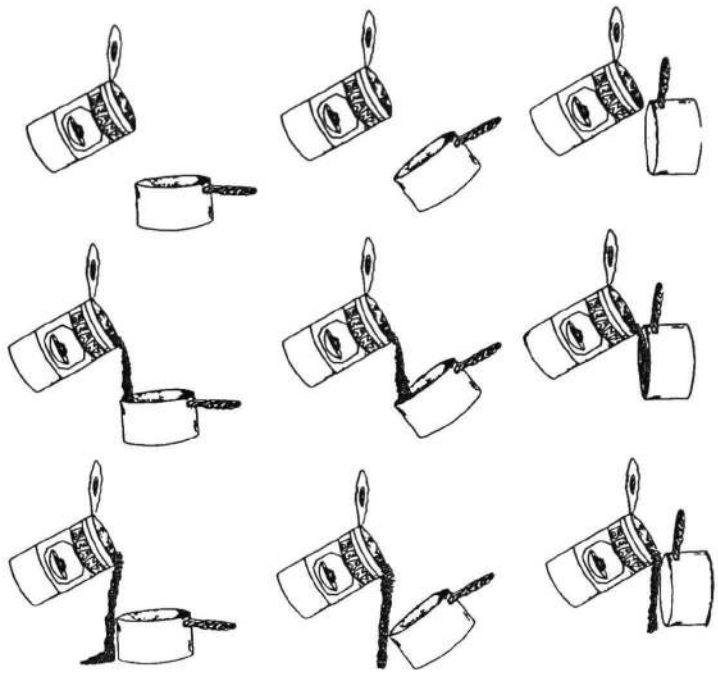


Figure 3: Examples from Material Set 2

The test materials were divided into two parts. One copy of each picture (with one pair of prepositions) appeared in part one and the other copy of the picture (with the other pair of prepositions) in part two. Half of the participants saw part one first and the other half saw the second part first (though participants were not aware of the two parts). Additionally, the materials were randomised in a stratified fashion. We created 9 groups of 8 pictures for each part. Each group had one picture from each material set, and corresponded to a different level of geometry and functionality. Then, each individual group was randomised before being grouped with another group. Each participant had a different grouping and randomisation. The end result of this process meant that the possibility of priming effects was minimised.

Results

The results for each set of materials are reported separately.

Material Set 1

A five way analysis of variance (fully within) was performed on the rating data. The variables were material type (umbrella/man, head/hat, shield/viking, visor/gardener), function (e.g., functional, non-functional and control), angle (canonical, 45°, or 90°), superior/inferior prepositions (over/above and under/below; higher than and lower than prepositions) and

functional/non-functional prepositions (over/under and above/below).

A main effect of function was found [$F(2, 72) = 82.41$, $p < 0.0001$]. Follow-up analysis using Tukey HSD tests revealed significant differences between all three levels of function. The highest ratings were given for the functional scenes, and the lowest ratings were given for the non-functional scenes. There was also a main effect of angle [$F(2, 72) = 213.22$, $p < 0.0001$]. As expected, the highest ratings were given for the canonical orientation and the lowest for the 90^{O} pictures. All three levels differed significantly from one another.

No main effect was found for the superior/inferior distinction [$F(1, 36) = 0.37$, $p > 0.05$]. However a main effect was found for the over/under-above/below comparison [$F(1, 36) = 76.07$, $p < 0.0001$]. Overall over/under were given lower ratings that above/below.

A significant interaction was observed between function and angle [$F(4, 144) = 5.36$, $p < 0.001$]. For the 45 degree and 90 degree angles, the ratings for functional, non-functional and control scenes differed significantly from one other. With the canonical position, there was no significant difference between the functional and control scenes although the non-functional scenes did differ significantly from the other two.

There were also significant interactions between the functional/non-functional preposition distinction and angle [$F(2, 72) = 122.15$, $p < 0.0001$] and function [$F(2, 72) = 34.36$, $p < 0.0001$]. These interactions are displayed in Figure 4.

There were a number of materials effects and interactions. Not only was there a main effect of materials [$F(3, 108) = 80.07$, $p < 0.0001$], but materials also interacted with function, angle and the functional/non-functional distinction. On examination all sets of materials behaved the same way with all the main variables - what differs between materials is the size of the effects although the direction remains the same in each case. It would appear that some sets of materials are more functional than others, and this should be noted in future studies.

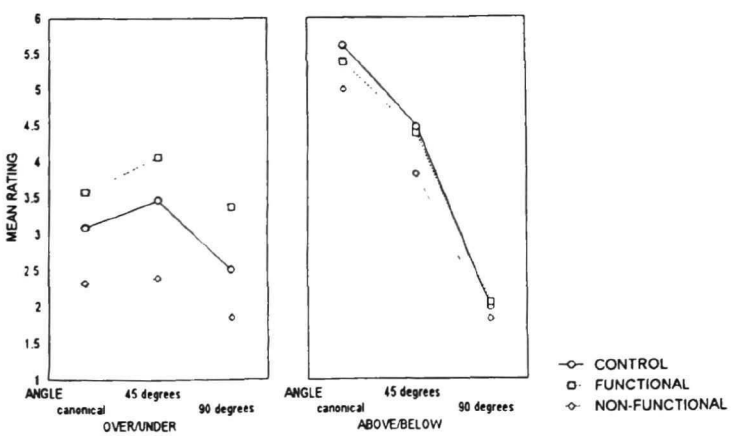


Figure 4: Interaction Between Functional/Non-functional Prep. and Function and Angle

Material Set 2

Again a five-way analysis of variance (fully within) was performed on the data). The variables were material type (tap/bucket, chute/skip, can/pan, bottle/glass), function (e.g., functional, non-functional and control), angle (canonical, 45^{O}, or 90^{O}), superior/inferior prepositions (over/above and under/below) and functional/non-functional prepositions (over/under and above/below). The results were very similar to those found with the first material set. Main effects of function [$F(2, 70) = 96.23$, $p < 0.0001$], angle [$F(2, 70) = 164.71$, $p < 0.0001$] and the functional/non-functional distinction [$F(1, 35) = 119.45$, $p < 0.0001$] were found, all in the same direction as those found with Material Set 1. Additionally there was a main effect of the superior/inferior distinction [$F(1, 35) = 5.24$, $p < 0.05$]. *Above* and *over* were given higher ratings that *below* and *under* overall, which is consistent with previous work (e.g., Seymour, 1974). Similarly, there was also an interaction between angle and the superior/inferior distinction [$F(2, 70) = 5.80$, $p < 0.01$].

There was a significant interaction between function and angle [$F(4, 140) = 10.47$, $p < 0.0001$]. Follow-up analysis revealed that all three levels of functionality differed significantly from one another in the predicted direction at every geometric position.

There were also significant interactions between function and functional/non-functional prepositions [$F(2, 70) = 35.86$, $p < 0.0001$] and angle and functional/non-functional prepositions [$F(2, 70) = 46.52$, $p < 0.0001$]. This pattern of results was the same as those found for Materials Set 1. Function has an effect with *over/under* but not with *above/below*. Conversely, angle had an effect with *above/below* but not with *over/under*. The three-way interaction between function, angle and functional/non-functional prepositions was also significant [$F(4, 140) = 7.26$, $p < 0.0001$]. This is displayed in Figure 5.

As with Material Set 1, there was a main effect of materials plus interactions between materials and function and angle. On examination all sets of materials behaved in the same way with all the main variables - what differs between materials is the size of the effects although the direction remains the same in each case.

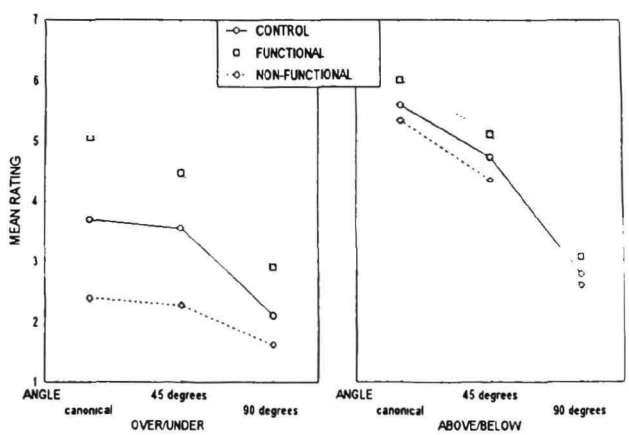


Figure 5: Interaction Between Functional/Non-functional Prep. and Function and Angle

General Discussion

The results across both sets of materials were very similar. Main effects of function and angle were found in both sets, demonstrating that functional relations and geometry are both important factors in determining the appropriateness of a preposition to describe a spatial scene.

With regards to geometry, the results were very similar to those found in the literature (Carlson-Radvamsky & Irwin, 1993, 1994; Hayward & Tar, 1995; Logan & Sadler, 1996). When the figure is displaced from the point directly above the central axis of the reference object, appropriateness ratings for suitable spatial prepositions decrease. Additionally, the study showed a main effect of function of similar magnitude to that found for the geometric manipulation. Participants gave significantly higher ratings to sentences corresponding to scenes where the functional relation between objects held, than to sentences corresponding to scenes where an object was shown not to be fulfilling its function.

The interaction between geometry and function also reveals that it is not the case that functional relations only become important when the prototypical geometric relation is not present. Functionality effects were present with both sets of materials at all three positions, not just in the marginal geometric cases.

The effects found in the experiment presented in this paper build on the findings obtained by Carlson-Radvansky and Radvansky (1996). These authors found that functional relations influenced frame of reference selection. Frame of reference ambiguity was absent in the present study, providing evidence that functional relations are crucial both not only in the choice of frames of reference but also to determine the appropriateness of a spatial term within a single frame of reference.

Although materials effects were observed across both sets, effects of functionality and geometry were in the same direction for all sets. It is worth noting, however, that the canonical position for the figure across scenes did differ, which may have lead to the material differences. For example, an umbrella is normally held directly above the head, whereas a shield is usually held in front of the body.

Given the existence of functionality effects in the present study, and previous research indicating that there are object-specific function effects with topological prepositions (Coventry et al., 1994) future studies need to control for the types of object relations used if geometry is to be the focus of attention.

It should be noted that most studies examining projective prepositions have focused on geometric relations. For instance, Logan and Sadler (1996) using abstract objects, showed typicality effects for projective prepositions. They propose that geometric templates are used to assess the appropriateness of spatial terms. However, this proposal should be treated with caution. It may be the case that such effects are only present with abstract objects where subjects distinguish between geometric regions as they have no other information to go on.

The present study has, for the first term, demonstrated the importance of both function and geometry in the comprehension of projective prepositions. Furthermore, clear evidence has been produced that some prepositions are more influenced by functional relations while others are more influenced by geometry. The rating of *over* and *under* across both sets of materials were influenced mainly by functionality, while *above* and *below* were mainly influenced by geometry. This pattern of results supports the findings of Coventry and Mather (in press), for *over* and *above*, but also extends the results to *under* and *below*. It may be the case that prepositions cluster into two groups: one where the meaning is primarily determined by the type of simple geometric construct, as proposed by Herkovits (1986), and the other where the meaning is primarily determined by a myriad of extra-geometric factors, which might include not only functional relations, but other contextual factors as well. Future research should examine this new distinction further.

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Appendix - Materials Used

Set 1:
Umbrella and man (with or without rain)
Shield and Viking (with or without spears)
Hard hat and workman (with or without brick)
Visor and gardener (with or without insect)

Set 2:
Glass and bottle (with or without wine)
Bucket and tap (with or without water)
Pan and can (with or without beans)
Skip and rubbish chute (with or without bricks)