ELSEVIER
Cognition 72 (1999) 167–189
COGNITION
www.elsevier.com/locate/cognit

In and *on*: investigating the functional geometry of spatial prepositions

Simon Garrod*, Gillian Ferrier, Siobhan Campbell

Human Communication Research Centre, University of Glasgow, 56 Hillhead Street, Glasgow G12 9YR, UK

Received 26 February 1999; accepted 1 June 1999

Abstract

Spatial prepositions such as *in* and *on* seem to denote semantically indeterminate spatial relations. This reflects, in part, the physical relationships between the objects in the scenes that they are used to portray. We argue that such physical relationships are best represented in terms of an inherently dynamic *functional geometry* which incorporates notions of location control. Two experiments are reported. They investigate the degree to which independent judgements of location control predict choice of description across a range of scenes. The results show that judgements of location control predict viewer's choice of description under certain circumstances. In the absence of prototypical geometric relations, control information has a strong influence on choice of description. However, when the scenes portray prototypical geometric relations, control information has less of an effect. The results support a hybrid account of the semantic representation underlying the prepositions with both a geometric and a functional component to it. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Spatial prepositions; Functional geometry

1. Introduction

In any language so far studied locative expressions are few in number but allow for a wide range of uses[1] (Landau & Jackendoff, 1993). This discrepancy between the small number of apparently simple spatial distinctions being made in language and the wide variety of different uses to which locative expressions are put presents a

* Corresponding author. Fax: + 44-141-330-3987.
E-mail address: simon@psy.gla.ac.uk (S. Garrod)

[1] The Oxford English Dictionary devotes 7 pages to *in* alone.

PII: S0010-0277(99)00038-4

challenge for semantic analysis. On the one hand, the intuitive simplicity of prepositions like *in* and *on* would indicate a correspondingly simple semantic analysis; but on the other, their wide range of usage seems to confound any straightforward treatment of their meaning (Herskovits, 1986; Vandeloise, 1991). To illustrate the problem, consider the description 'the pear is in the bowl' in relation to the first three scenes depicted in Fig. 1. Whereas the description fits case (a), it seems less appropriate for (b) or (c). Yet, the geometric relationship between pear and bowl is very similar in both (a) and (b), and, in (c) the pear is located geometrically inside the bowl, whereas in (a) it is not (see Garrod & Sanford, 1989).

In the light of such examples the present paper addresses the following question: Is the underlying representation of *in* and *on* geometric or does it also reflect functional relations between the objects in the scenes portrayed? In attempting to answer

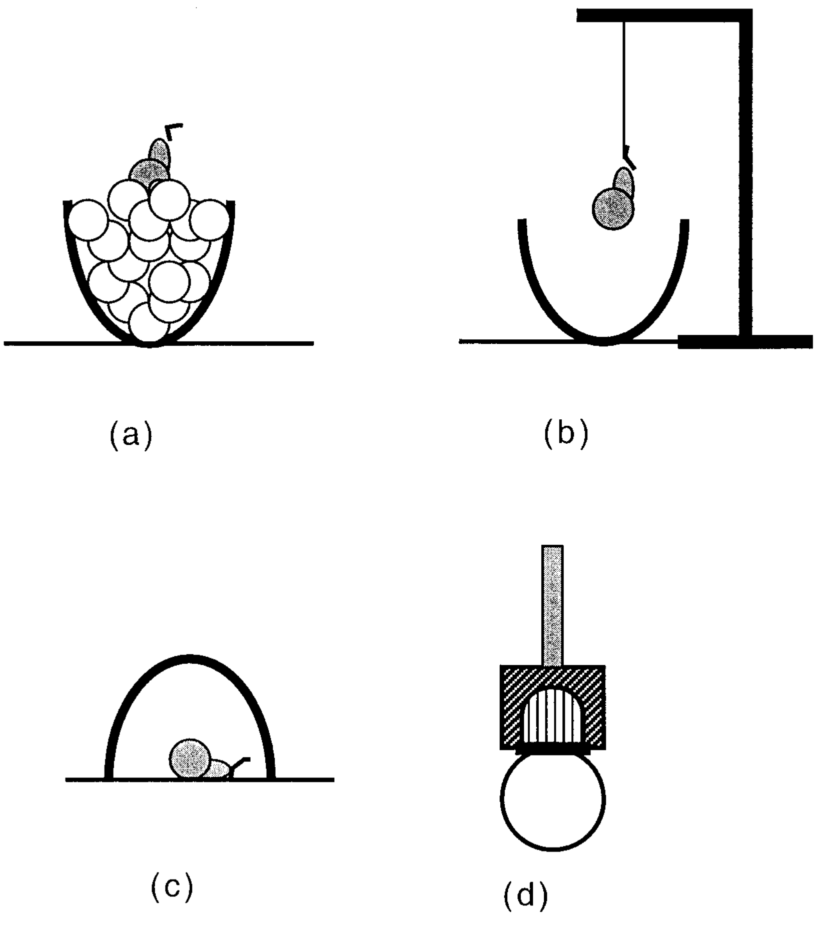

Fig. 1. Different arrangements of objects for which the description 'the pear is in the bowl' may or may not be appropriate.

this question we report experiments that measure viewers' confidence in different spatial descriptions of a number of scenes together with experiments that tap their perception of the functional relations being portrayed. The results point to a hybrid account of the underlying representation, incorporating both geometric and functional information.

The paper is organised into three main sections. First, there is a brief description of the various approaches that theorists have taken to the analysis of the prepositions *in* and *on*. This compares approaches that concentrate on a geometric characterisation of their core meaning with more functional approaches and considers how each deals with the problem of geometric indeterminacy. We then report two experiments that test the geometric and functional accounts in relation to a viewer's choice of alternative description for different scenes. On the basis of the results from these experiments we then consider how functional and geometric components of meaning might interact in defining the prepositions.

2. The semantics of *in* and *on*

Accounts of the semantics of locatives, such as *in* or *on,* differ in terms of the nature of the representation assumed to underlie their meaning. Broadly speaking there are two kinds of account: geometric accounts, which treat the underlying representation in terms of basic geometric relations, and functional accounts, which assume that the prepositions reflect functional or physical relations between objects in the world.

2.1. Geometric accounts

The traditional approach to the semantics of spatial prepositions is to treat them as expressing geometric relations (Cooper, 1968; Leech, 1969; Bennett, 1975; Miller & Johnson-Laird, 1976; Herskovits, 1986). Thus, each preposition is associated with a representation that can be decomposed into spatial primitives, expressed in terms of geometric or topological relations such as *enclosure* and *spatial contiguity.*

Table 1 summarises the definitions given for *in* and *on* according to the five accounts cited above. Although the definitions are not identical, there is a common theme running through all of them. For *in*, the referent x (i.e. the subject of the preposition) must be *included* in, *enclosed* by or *interior* to the relatum y (i.e. the object of the preposition). For *on*, the assumed representation is one of *contact* or *contiguity* of the surfaces of referent and relatum together with the additional constraint of *support* for some of the definitions. Thus the semantic representation of the prepositions is primarily geometrical, expressed through topological relations such as enclosure or spatial contiguity.

These accounts have the virtue of defining the prepositions in terms of intuitively simple geometric relations. However, they do not fare so well when it comes to accounting for the range of locative uses. For example, the central topological constraint of enclosure or spatial inclusion for *in* does not apply in case (a) of Fig. 1, where we can quite naturally describe the pear as in the bowl, but does

Table 1
Geometric definitions of the prepositions *in* and *on*

Bennett (1975)	
in *y*	Locative (interior (*y*))
on *y*	Locative (surface (*y*))
Cooper (1968)	
x **in** *y*	*x* is located internal to *y*, with the constraint that *x* is smaller than *y*
x **on** *y*	A surface of *x* is contiguous with a surface of *y*, with the constraint that *y* supports *x*
Leech (1969)	
x **in** *y*	*x* is 'enclosed' or 'contained' either in a two-dimensional or in a three-dimensional place *y*
x **on** *y*	*x* is contiguous with the place of *y*, where *y* is conceived of either as one-dimensional (a line) or as two-dimensional (a surface)
Miller and Johnson-Laird (1976)	
in (*x, y*)	A referent *x* is **in** a relatum *y* if: [PART (*x,z*) & INCL (*z,y*)]
on (*x,y*)	A referent *x* is 'on' a relatum *y* if: (i) (INCL (*x*, REGION (SURF (*y*))) & SUPRT (*y*, *x*); otherwise go to (ii) PATH (*y*) & BY (*x*, *y*)
Herskovits (1986)	
in (*x, y*)	Inclusion of a geometric construct of *x* in a one-, two-, or three-dimensional geometric construct of *y*
on (*x, y*)	For a geometric construct *x* to be contiguous with a line or surface *y*; if *y* is the surface of an object O_y, and *x* is the space occupied by another object O_x, for O_y to support O_x

apply in case (c), where the description seems much less appropriate. A number of researchers have recently highlighted similar problems in relation to geometric accounts of the meaning of *on* (Garrod and Sanford, 1989; Vandeloise, 1991; Coventry, Carmichael & Garrod 1994; see also Bowerman, 1996a). So the question arises as to how to explain the apparent geometric indeterminacy of these locatives while still retaining the idea that they capture intuitively simple relations.

Part of the problem is with the definition of the geometrical relations themselves. Crangle and Suppes (1989) (see also Suppes, 1991) point out that relations like *enclosure* and *contiguity* presume geometric invariants which prove difficult to define within standard point and line geometries. In turn, this makes it difficult to say precisely what is meant by enclosure or contiguity in the definitions. In order to overcome this problem, Cohn and colleagues (e.g. Cohn, Bennett, Godday & Gotts 1997) have recently developed a qualitative geometry of space which treats 'regions of space' as fundamental (Cohn, 1996). This qualitative geometry, like Allen's qualitative calculus of temporal relations (Allen, 1983), is well designed for capturing semantic distinctions (Aurnague, 1995). And as we shall see, it goes some way towards explicating the differences between the scenes in Fig. 1.

Cohn et al. (1997) define a wide range of spatial relations in terms of just two primitives: *connection* and *convexity*. Connection is a broadly defined relation that ranges from simple contact or overlap between regions to their identity. Convexity, on the other hand, relates to the presence in a region of interior spaces, defined in relation to what Cohn calls the *convex hull* of the region: the smallest convex region to also include the region in question. In this geometry, there are a number of ways that one object can be represented as *in* another object or *in* other objects, which reflect different degrees and kinds of enclosure. In the strongest version a region can be topologically inside another – when one region completely surrounds the other – as in 'the jam in the closed jar' or 'the insect in the amber' (see Fig. 2d). In the weaker versions one region is *in* another when it is a sub-part of or overlaps with the region defined by the other's convex hull. Thus the black ellipse is partially *in* the grey ellipse in Fig. 2a; in Fig. 2b it is geometrically enclosed, and, in Fig. 2c it is enclosed by the group of four grey circles as part of their *scattered inside*.[2] The first case is exemplified by 'a flower in a vase', whereas the third would underlie 'a bird in a tree' or 'an island in an archipelago'. There are other kinds of enclosure for three-dimensional regions that can be represented within this system. For instance, there is a contrast between *tunnel* and *containable* insides, which underlies the distinction between putting your finger into the handle of a teacup as opposed to pouring the tea into the cup (Fig.2e).

Armed with this array of basic geometric relations one can define a range of different degrees of enclosure to reflect different degrees of spatial constraint in the real world. Take for example situations like that portrayed in Fig. 1a. Here it seems that we have to compose two notions of enclosure. First, the target referent (in this case a pear) displaces a region which is in a scattered inside defined by the convex hull of the other fruit. Second, this latter region is partially inside the convex hull of the bowl. So by application of transitivity the target becomes weakly enclosed by the bowl.

There are also similar considerations in defining the contact relation for definitions of *on*. However, in this case the issue is in determining the extent to which the referent can be considered remotely in contact with the relatum (Miller & Johnson-Laird, 1976; Herskovits, 1986). For example, a book may be remotely in contact and supported by a table even when one or more books intervene. Thus, spatial contact, like spatial enclosure, may be graded by degree and this could lead to different degrees of confidence in the use of prepositions such as *in* or *on* depending upon the situation being described.

However, even with this more detailed analysis of primitive geometric relations, there are contrasts in usage of the prepositions which cannot readily be explained. For instance, it is difficult to account for the fact that the light-bulb in Fig. 1d is naturally described as 'in the socket' whereas the pear in Fig. 1c is not normally

[2] The *scattered inside* of a group of objects is defined by the convex hull of the group as a whole (i.e. the smallest convex region which includes all the regions in the group).

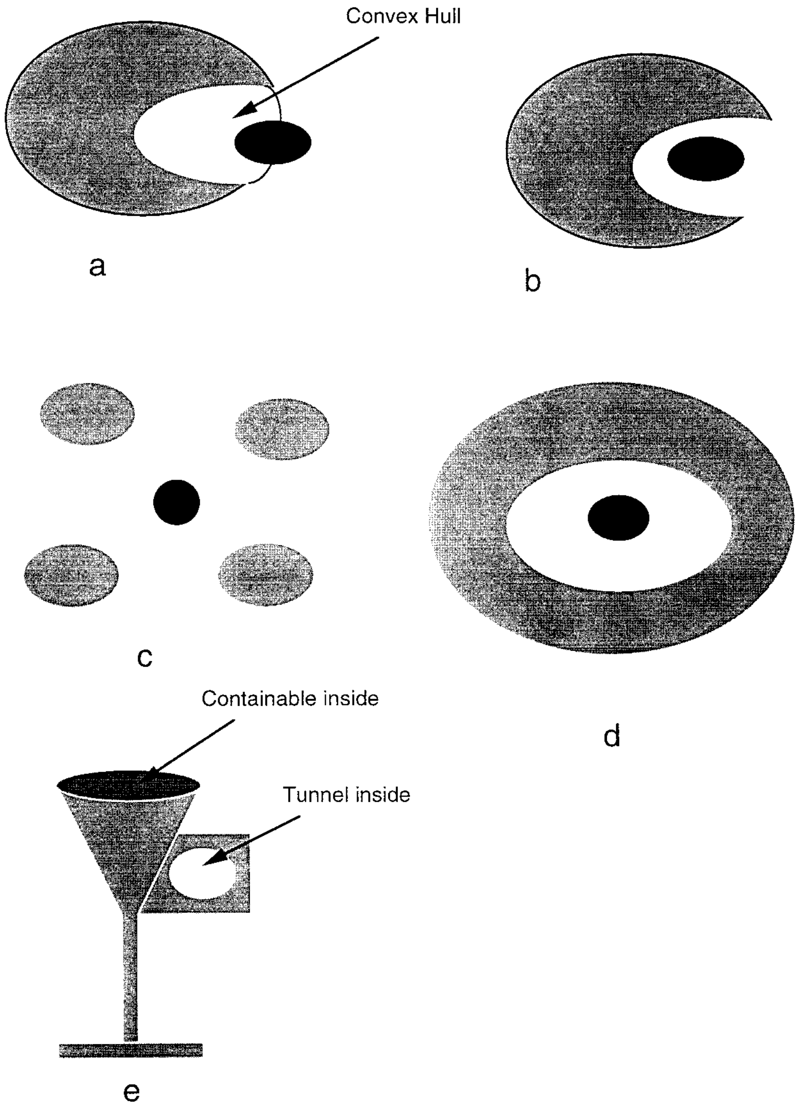

Fig. 2. Arrangements of **regions** to illustrate different degrees of enclosure according to the Region Connection Calculus of Cohn (1996) representing: (a) partial geometric enclosure, (b) complete geometric enclosure, (c) scattered geometric enclosure, (d) topological enclosure, and, (e) containable and tunnel insides.

described as ‘in the bowl’, despite the fact that the light-bulb is only partially enclosed, whereas the pear is completely geometrically enclosed. Such limitations on purely geometric accounts have led to the development of functional accounts as an alternative way of characterising the meaning of prepositions such as *in* and *on*.

2.2. Functional accounts

In the geometric accounts described above reference is sometimes made to what are really functional relations. For example, Cooper (1968); Herskovits (1986); Miller and Johnson-Laird (1976) all include the functional relation *support* as a component of one sense of the preposition *on*. Miller and Johnson-Laird (1976) also invoke a functional concept of *region* as part of the meaning of a number of locatives, where *region* in their sense represents the range within which an object can normally interact with other objects. However, these functional characteristics are only considered as additional special constraints on the essentially geometric definitions of the prepositions rather than the primary source of their meaning.

More recently, a somewhat different approach has emerged that treats the basic meaning of locatives in functional terms (Talmy, 1988; Garrod & Sanford, 1989; Vandeloise, 1991; Coventry et al., 1994; Aurnague, 1995). Such accounts assume that the spatial relations associated with the interpretation of the different prepositions reflect spatial constraints on what are primarily functional relations between referents and relata.

The functional account that we use as the reference for the experimental studies reported here comes from an analysis by Garrod and Sanford (1989). Like Vandeloise, we argued that the meaning of many locatives comes from physical constraints on the relationship between the objects being described. One such constraint is *location control*: the way in which objects are seen to control the location of other objects through physical forces in the world. Thus underlying the preposition *in*, there seems to be a relation of functional containment: If Y **fcontains** X, then Y's location controls X's location by virtue of *some degree* of spatial enclosure of X by Y.

According to this account, inness reflects a certain kind of control whereby a container constrains the location of its contents. For a person to be 'in a queue' means that the queue and its movement predicts that person's location; for a word to be 'in a margin' means that the word's location on the page is constrained by the position of the margin (e.g. if in a word processing system you move the margin it should still delimit the position of the word); for a pear to be in a bowl means that when the bowl is moved the pear should move with it.

The fcontainmnent control relation can explain the difference in perceived inness for the pear in Fig. 1a as compared to Fig. 1b,c. Whereas movement of the bowl is seen as likely to produce correlated movement of the pear in Fig. 1a, in Figs. 1b and c it is seen as less likely to have such an effect. This is because in the latter two cases the pear's location is primarily controlled either by the string from which it is hanging (Fig. 1b) or the surface on which it is resting (Fig. 1c). Fcontainment can also explain the difference between the situation in Fig. 1d, with the light-bulb, and in Fig. 1c, with the pear, since the socket controls the location of the bulb (i.e. when the socket is moved the bulb should move with it), but the bowl does not control the location of the pear.

A similar functional geometric relation can be defined for the meaning of the preposition *on*, in relation to functional support: If Y **fsupports** X, then Y's location controls the location of X with respect to a unidirectional force (by default gravity) by virtue of *some degree* of contact between X and Y. If X is *on* Y, then the object Y **fsupports** the object X. Thus, if a picture is on a wall or a light on a ceiling, then the wall and ceiling indirectly stop the picture and light from falling; if a ball is on a string and you are spinning it around your head, then the string fsupports the ball against a centrifugal force – note that when you release the string, it is now more natural to say the string is on the ball rather than vice versa – and if a kite is on a string, the string fsupports the kite against the force of the wind.

Thus, functional geometric representations of the kind discussed above have two components: a functional component concerned with location control, and, a geometric component concerned with the geometric relationship by virtue of which the control can take effect.

Given these two rather different kinds of account of the underlying semantic representations of spatial prepositions, it is of some interest to establish the role of geometry and function in determining our use of prepositions like *in* and *on*. There are three possibilities: (1) that use is determined solely by the perceived geometry of the situation, (2) that it is determined by the perceived functional relations in the situation (e.g. by such factors as fcontainment or fsupport), or, (3) that use reflects both factors but under different circumstances (e.g., geometry could dominate for the use of *in* for scenes where there is prototypical or strong enclosure, but function could dominate otherwise). The experiments reported here were designed to differentiate between these three alternatives for use of *in* and *on*.

3. Experiments with IN and ON

The correlation between function and geometry makes it difficult to discriminate between purely geometric accounts and those based on a functional geometry of the kind described above. In general, location control through fcontainment or fsupport goes with the geometry of enclosure and contact. So the experiments we report here use as stimuli scenes in which functional information can be manipulated independently of geometrical information. We can then record two kinds of confidence judgements about those scenes: (1) confidence in different locative descriptions, and, (2) confidence in the degree to which the location of a referent is controlled by that of the relatum or vice versa. If the functional account is correct, then estimates of the degree of control should predict confidence in the use of the appropriate prepositions, irrespective of the geometry of the scenes. If the pure geometric account is correct, then there should be no independent contribution of degree of control to confidence in the descriptions. Finally, if degree of control only contributes to use under certain geometric configurations, this would point to a hybrid account.

Experiment 1 investigates confidence in *in* descriptions and its relation to *fcontainment*. Experiment 2 investigates confidence in *on* descriptions in relation to *fsupport*.

4. Experiment 1

This experiment was based on a series of scenes with a glass bowl containing Ping-Pong balls (see Fig. 3). Three factors were manipulated across the series: the position of the target Ping-Pong ball relative to the bowl, the degree to which it was surrounded by other balls and whether or not it was attached to an alternative source of control in the form of a wire. Previous pilot experiments had shown that all these manipulations affected a viewer's confidence in the description 'the ball is in the bowl'. The question of interest was whether this range of confidence could be accounted for in terms of a viewer's judgement of the control relation between bowl and Ping-Pong ball.

In order to investigate the relationship between confidence in descriptions and judgements of control we used two measures. One group of viewers made confidence judgements about the use of the preposition *in* for descriptions of the scenes (Expt. 1a) and another group judged how dynamic changes in the scenes would affect the geometric relation between the ball and bowl (Expt. 1b). If the functional account is correct, then judgements about the consequence of moving the bowl containing the target Ping-Pong ball should predict confidence in judgements of descriptions containing *in*.

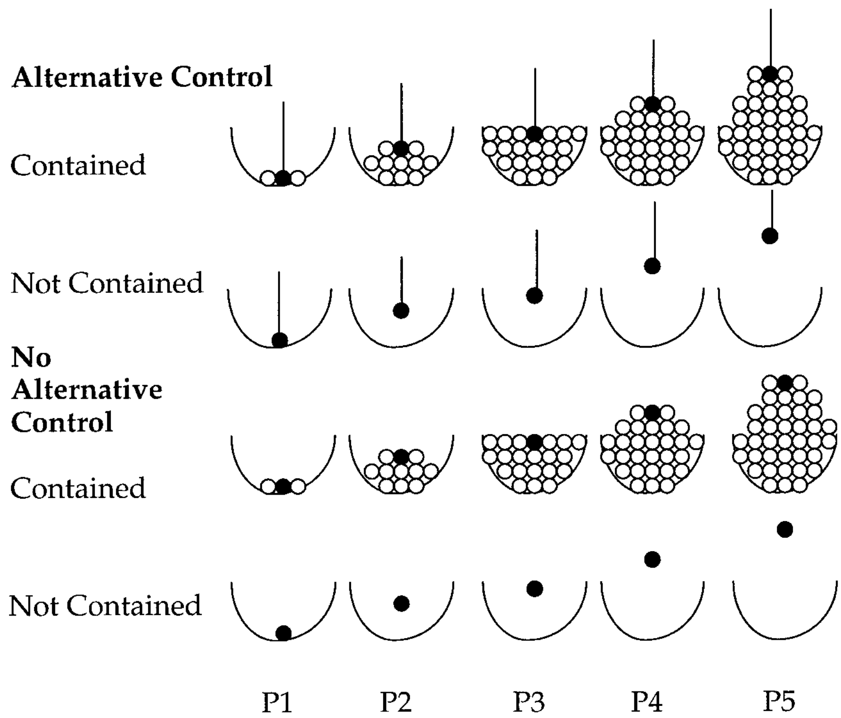

Fig. 3. The different arrangements of Ping-Pong ball and bowl used in Expt. 1.

4.1. Experiment 1a

4.1.1. Method

Participants. The 53 participants were all undergraduates at the University of Glasgow and were paid £2.50 for participating in the experiment. Twenty-three of them were male and 30 were female. They were tested in groups of five.

Materials and design. The scenes of bowl, Ping-Pong balls and wire were all videotaped. For the Position variable there were five relative positions of the target Ping-Pong ball and the bowl (as shown in Fig. 3). They varied from having the ball sitting on the bottom of the bowl (Position 1), in between the rim and the bottom (Position 2), level with the rim (Position 3) and two more positions above the rim to the same degree (Positions 4 and 5). There were two additional manipulations. First, for each position the target ball could either be supported by other balls (Contained) or standing alone (Not Contained), and second, the target ball could either be clearly attached to a wire, which was hanging from a solid metal support (Alternative Control), or unattached (No Alternative Control).

The various arrangements are shown schematically in Fig. 3 and lead to a three-way $2\times2\times5$ design with Containment, Control and Position as factors. These scenes were all video-recorded onto a master-tape for presentation in both Expts. 1a and 1b.

Procedure. The participants were tested in groups of 5. First they were given an identical 7-page questionnaire which included written instructions about the experiment. This indicated that they would be seeing a sequence of video clips showing scenes of Ping-Pong balls and glass bowls. The instructions also made it clear that one of the balls would be identified with a pointer and that this was the target for their ratings of different descriptions of the scenes. The booklet contained a list of descriptions like that shown below but with a different random order for each scene:

The ball is **above** the bowl	1 2 3 4 5
The ball is **on** the bowl	1 2 3 4 5
The ball is **under** the bowl	1 2 3 4 5
The ball is **in** the bowl	1 2 3 4 5
The ball is **over** the bowl	1 2 3 4 5
The ball is **below** the bowl	1 2 3 4 5

The subjects were then instructed to rate the appropriateness of each description for each of the scenes that they would see and it was stressed that the scale must be rated for each statement per scene (from highly unlikely = 1 to most likely = 5).

These instructions were explained verbally and subjects were able to ask any questions about the procedure. They were then played the video-tape and after each scene appeared (lasting about 5 s), they were given a period of 20 s to fill out their ratings before moving on to the next scene.

4.1.2. Results and discussion

The mean confidence scores for the judgements of *in* descriptions are shown in Fig. 4 according to all the factors in the design. These data were subjected to $2 \times 2 \times 5$ repeated measures ANOVA with Control, Containment and Position as factors.

All the manipulations produced reliable main effects. Having an alternative source of control reduced confidence in *in* (Alternative control = 2.9, no alternative control = 3.1; $F_{(1,52)} = 6.94$, $P < 0.01$). A similar effect occurred with the containment manipulation (Contained = 3.4, not contained = 2.6; $F_{(1,52)} = 6.19$, $P < 0.05$), as well as for position (P1 = 4.8, P2 = 4.6, P3 = 2.2, P4 = 1.9, and P5 = 1.6; $F_{(4,208)} = 71.43$, $P < 0.001$).

There was also a three-way interaction between the factors ($F_{(4,208)} = 14.34$, $P < 0.001$) as well as separate two-way interactions between each pair of factors in turn (for control × containment, $F_{(1,52)} = 17.37$, $P < 0.001$; for control × position, $F_{(4,208)} = 2.67$, $P < 0.05$, and for containment × position, $F_{(4,208)} = 8.29$, $P < 0.001$). This complex pattern of results can be explained by considering how each factor is operating at the different positions. First, it seems that for positions 1 and 2 the geometry dominates. So there are no separate effects of containment or alternative control. However, for all the positions at or above the rim the two additional factors become important. There is a reliable effect of containment for all these positions (Post hoc contrasts of containment at positions 3, 4 and 5, $F_{(1,208)} > 69.74$, $P < 0.001$, for all contrasts). Similarly there is a reliable effect of alternative control for positions 3 and 4 (post hoc contrast of control at position 3, $F_{(1,208)} = 23.1$, $P < 0.001$, at position 4, $F_{(1,208)} = 4.9$, $P < 0.05$). However, it is clear that the alternative control manipulation is only effective overall when there is also containment (post hoc contrast of control with containment, $F_{(1,208)} = 11.02$, $P < 0.01$).

The results of this study give a mixed picture of the role of function and geometry

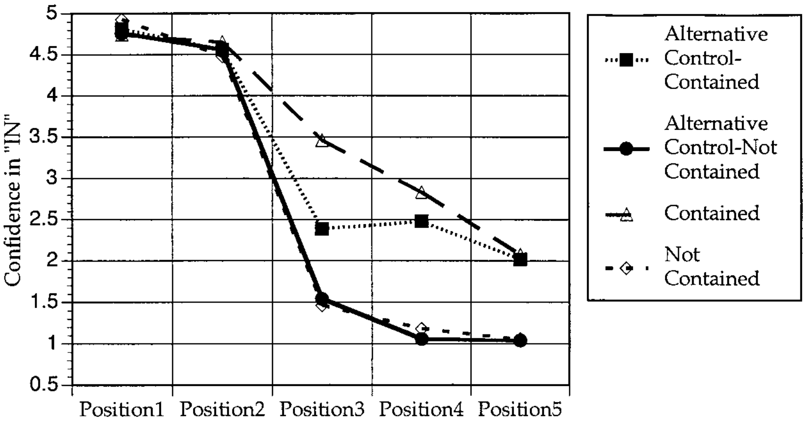

Fig. 4. Confidence in the description 'the ball is **in** the bowl' across the five positions and the different conditions tested in Expt. 1a.

in determining confidence in use of *in*. On the one hand, it seems that with complete enclosure of the ball by the bowl viewers judge the ball to be ‘in the bowl’ irrespective of additional factors which might be expected to influence judgements of location control. On the other hand, as soon as enclosure is weakened, in Cohn et al. (1997), terms, location control factors seem to exert a strong influence. However, to gain a clearer picture of what is happening here, we need to establish the degree to which the different scenes suggest differences in location control of the ball by the bowl. Expt. 1b was designed to do this.

4.2. Experiment 1b

4.2.1. Method

Participants. The 67 participants were undergraduates at the University of Glasgow and were paid £1.50 for participating. There were 39 females and 28 males.

Materials and design. The basic materials were exactly the same as those used in Expt. 1a, but with the addition of an extra scene involving the glass bowl being moved laterally by hand at a reasonable rate. This was to act as a model for eliciting the judgements about the consequences of the dynamic manipulation. Again the different scenes generated a $2 \times 2 \times 5$ design with Control, Containment and Position as factors.

Procedure. For each trial the judges were shown one of the video scenes for 5 s then given a video demonstration of the type of movement that they were to judge. This was done by presenting an empty bowl being moved sideways at a reasonable rate. They were then required to make a choice between two possible outcomes of the movement: either NO CHANGE in the arrangement of bowl and target ball following a movement of that kind or CHANGE in the arrangement following the movement.

4.2.2. Results

Each subject’s responses were organised according to the design of the experiment and the overall proportion of subjects who indicated that the ball and bowl would remain in the same relative position (i.e. No Change) is shown accordingly in Fig. 5. Pooled frequency ratings for ‘no change’ judgements were compared using χ^2 statistics for the main contrasts in the experiment. Scenes where there was containment led to significantly higher ‘no change’ frequencies than non containment scenes (containment = 0.681, no containment = 0.434: $\chi^2_{(1)} = 81.36$, $P < 0.001$); scenes with alternative control led to significantly lower no change frequencies (alternative control = 0.458, no alternative control = 0.657; $\chi^2_{(1)} = 52.708$, $P < 0.001$) and there was an overall effect of position ($\chi^2_{(4)} = 224.506$, $P < 0.001$). Breaking the position effect down further revealed effects for P1 versus P2 (P1 = 0.858, P2 = 0.739; $\chi^2_{(1)} = 11.143$, $P < 0.01$), P2 versus P3 (P2 = 0.739, P3 = 0.396; $\chi^2_{(1)} = 81.4$, $P < 0.001$) and P4 versus P5 (P4 = 0.396, P5 = 0.343; $\chi^2_{(1)} = 6.29$, $P < 0.05$).

So it is apparent that the various manipulations of geometry and alternative control had clear effects on viewers’ judgements of the degree to which the relatum

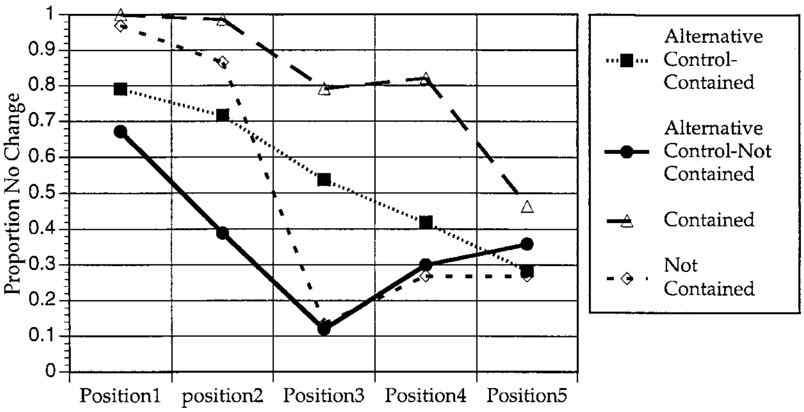

Fig. 5. Proportion of subjects who predicted that the ball and bowl would remain in the same relative position following movement for the conditions in Expt. 1b.

controlled the location of the referent. The crucial question is how this measure of location control predicts the range of confidence in the descriptions using *in* that were collected in Expt. 1a. This is considered below.

4.3. Discussion and comparison of Expts. 1a and 1b

Comparing the confidence measures of descriptions of *in* (Expt. 1a) with the independent dynamic judgement results (Expt.1b), highlights the contrast between scenes where the ball is below the rim of the bowl as opposed to those where it is at or above the rim. When the target is below the rim, viewers have a high confidence in the *in* descriptions irrespective of the other manipulations. However for the independent judgements (see Fig. 5) both containment and alternative control do have an influence at these positions. Turning to the scenes where the ball is at or above the rim, there is a much stronger relationship between the pattern of independent judgements and confidence in the *in* descriptions. For instance, both independent judgements and confidence in *in* show the same effects of alternative control.

Fig. 6 shows the correlation between the two data sets with $r_{(18)} = 0.832$ ($P < 0.001$). It is interesting to note that judgements of control across a wide range predict confidence in the use of *in* across a wide range despite the fact that they do not do a particularly good job when confidence in *in* descriptions is high. We believe that this result clearly implicates location control in the representation of the semantics of *in*. However, the comparison also highlights the fact that the geometric enclosure component of the representation can exert a strong independent influence in cases where the referent is geometrically enclosed by the relatum. This issue will be taken up in the final Discussion.

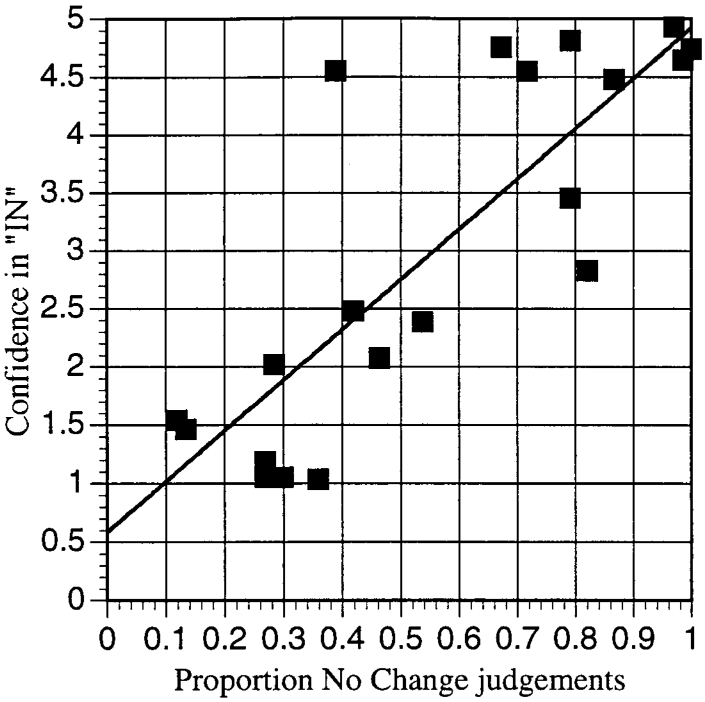

Fig. 6. Correlation between proportion of No Change judgements (Expt.1a) and confidence in *in* judgements (Expt. 1b).

5. Experiment 2

Experiment 2 was designed to test directly predictions about fsupport and confidence in the use of *on*. The rationale was similar to that of Expt. 1. A set of scenes were devised where the geometric relationship between referent and relatum was held constant while manipulating other features of the scenes which might be expected to indicate alternative means of support. In Expt. 2a we collected data on confidence in *on* descriptions for the scenes, and in Expt. 2b we collected independent judgements about what would happen, in these same scenes, if the relatum (i.e. primary support) were to be removed.

5.1. Experiment 2a

5.1.1. Method

Participants. The 70 viewers were all undergraduates at the University of Glasgow and were paid £2.50 for participating in the experiment.

Materials and design. The scenes we recorded contained a heavy weight (the referent) which could be placed on a primary support, a rigid wooden plank (the

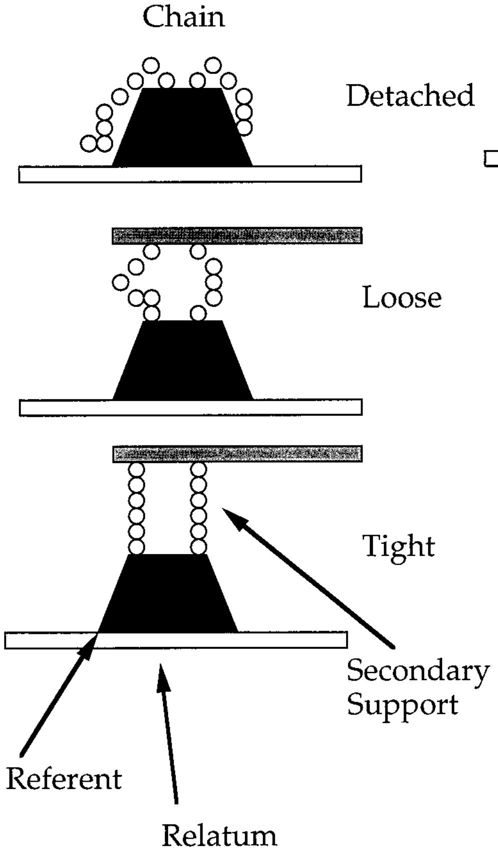

Fig. 7. Arrangement of weight, secondary support and primary support in the scenes used in Expt. 2.

relatum). The manipulations related to different ways in which the weight was attached to a secondary support. The design had the two factors illustrated in Fig. 7. First, there was the means of the secondary support which could either be a piece of string or a chain, and, then there were three degrees of secondary support: the chain or string could be loosely attached to the weight but otherwise detached, or, loosely attached to the weight and also attached to a visible secondary support, or, attached in this way but taut (detached, loose, tight). So there were two ways the importance of secondary support was manipulated with each expected to have some influence on judgements of alternative location control. The six scenes created by these combinations were recorded onto a master tape containing an additional 35 scenes from another experiment and presented to viewers for judgements of confidence in *on* descriptions (Expt. 2a) or independent judgements of alternative location control (Expt. 2b).

Procedure. The procedure was the same as that used in Expt.1a with subjects required to indicate the appropriateness of the five alternative prepositions as descriptors of the referent's spatial location relative to the relatum. An example set of items is shown below.

The weight is **above** the plank
The weight is **on** the plank
The weight is **under** the plank
The weight is **in** the plank
The weight is **over** the plank
The weight is **below** the plank

As in Expt. 1a, they were presented in a random order for each scene.

5.1.2. Results and discussion

The confidence judgements of *on* descriptions were organised according to the six conditions in the design and are shown in Fig. 8. These were analysed according to the 2 factors of Means and Degree of secondary support in a 2×3 ANOVA design with repeated measures.

The only reliable main effect proved to be degree of support with $F_{(2,68)} = 4.22$ ($P < 0.05$). Furthermore, each pair-wise contrast for degree of support given the two means of support was also significant with $F_{(1,68)} > 5.52$ ($P < 0.05$) for all contrasts. So the degree of secondary support proved to be the most important factor in predicting confidence.

As with *in* it seems that location control information affects a viewer's confidence in descriptions containing *on*. When a referent is seen to have an alternative means of support this reduces confidence in *on* descriptions given the same geometric relationship between the referent and relatum. However, it is also important to

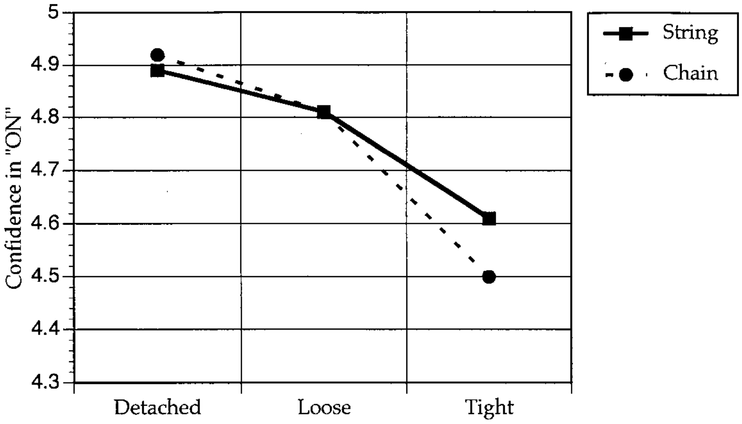

Fig. 8. Confidence in the description 'the weight is **on** the plank' for the different conditions of Expt. 2a.

establish the degree to which viewers will judge this alternative support as controlling the location of the referent. Expt. 2b was designed to do this.

5.2. Experiment 2b

5.2.1. Method

Participants. The 37 viewers were all undergraduates at the University of Glasgow and participated as volunteers in the experiment. There were 20 females and 17 males.

Materials and design. The materials were identical to those used in Expt. 2a. So the six scenes conformed to a 2 × 3 design with Means of Support (string or chain) and Degree of Support (detached, loose or tight).

Procedure. The procedure was basically the same as that used in Expt. 1b except that the subjects were asked to make their judgements on the basis of the question 'What do you think would happen to this scene if the plank was removed?' They then had to choose for each scene between the following alternatives: (1) No change in the position of the weight after the plank is removed, or (2) Change in the position of the weight after the plank is removed.

5.2.2. Results

The frequency of subjects choosing Change dynamic judgements were sorted according to the factors in the experiment and are shown for all the conditions in Fig. 9. Again pooled frequencies were analysed with χ^2 statistics. Both alternative control manipulations proved to have a significant influence on the dynamic judgements. Means of support produced a reliable difference in pooled frequencies with $\chi^2_{(1)} = 5.82$ ($P < 0.05$) as did degree of support with $\chi^2_{(1)} > 16.06$ ($P < 0.001$) for all comparisons of tightness of secondary support.

Again it seems that the manipulations of alternative support produce a range of

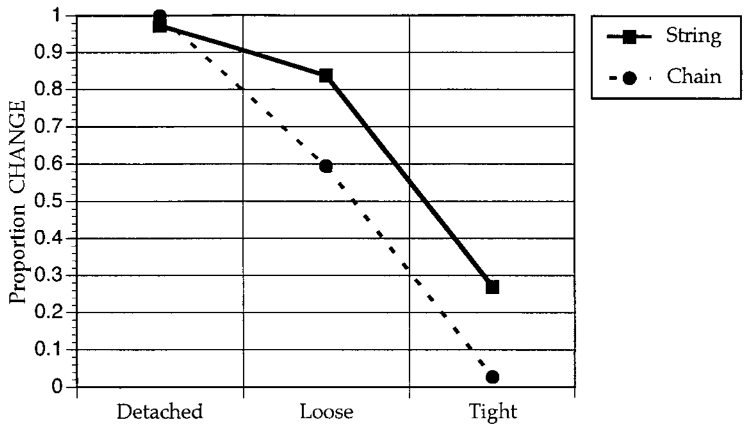

Fig. 9. Proportion of subjects who predicted that the weight would remain in the same position (No Change) following removal of the primary support in Expt. 2b.

judgements about the degree to which the relatum might control the referent's location with respect to gravity. Perceptually robust supports such as a chain are seen to exert stronger alternative influence on the referent's location than less robust secondary supports such as string. This influence is also strongly moderated by the tautness of the secondary support.

From the present point of view the crucial prediction about use of the preposition is that these effects should predict confidence in the use of *on*. The functional account would predict a systematic reduction in confidence in *on* descriptions as viewers increasingly judge the secondary support to be controlling the location of the referent.

5.3. Discussion and comparison of Expts. 2a and 2b

Experiments 2a and 2b were designed to compare judgements of degree of control with judgements of the appropriateness of different prepositional descriptions of the same scenes. As with the previous study we correlated the control judgements with the confidence of *on* descriptions, the result is shown in Fig. 10. As can be seen there is a strong correlation between the two ($r_{(4)} = 0.98$, $P < 0.01$). This shows a very strong positive relationship between the degree to which subjects judge the refer-

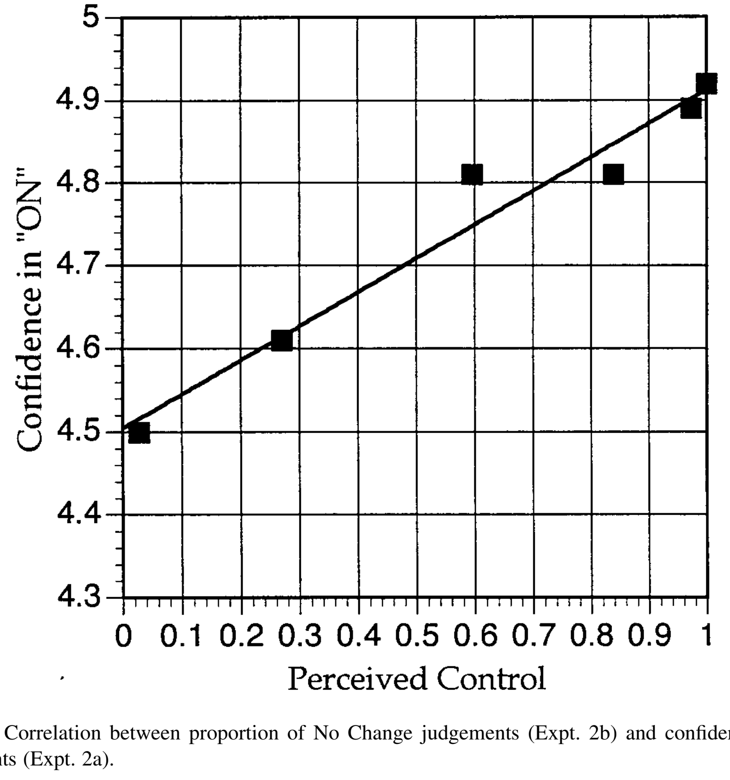

Fig. 10. Correlation between proportion of No Change judgements (Expt. 2b) and confidence in *on* judgements (Expt. 2a).

ent's location to be controlled by the primary support and their confidence that it is **on** that support. This is despite the fact that the referent was always above and in contact with the relatum.

The only difference in the pattern of results for the two studies is with the influence of means of support. Whereas means of support has a reliable effect on control judgements when the chain or string is tight, it has little effect on confidence in *on* judgements. This is possibly due to the interpretation of questions used for the control judgement task and the participants' criteria for judging the position of the weight unchanged after removal of the plank. In any case, it only produces a weak lack of overall correlation as can be seen in Fig. 10.

6. General discussion

The experiments reported here raise problems for any simple geometric account of the meaning of the prepositions *in* and *on*. They demonstrate that information about location control between referent and relatum can affect a viewer's confidence in the use of descriptions containing the prepositions. Furthermore, judgements of the strength of these control relations (measured in terms of the likelihood that relative position will change under physical manipulation) were good predictors of viewers' confidence in spatial descriptions of the same scenes. If we are to give a satisfactory definition of the prepositions, this kind of functional information must be taken into account in the semantic representation.

At the beginning of the paper, we outlined a functional geometric account of such an underlying semantic representation. It had two components: a functional component reflecting dynamic information about how the objects in a scene are likely to interact under different physical circumstances and a geometric component which captures the geometric relationships typically associated with these interactions. For *in* and *on* we argued that the functional component reflects different kinds of location control between the referent and the relatum,[3] whereas the geometric component reflects either some degree of regional enclosure, for *in*, or some degree of regional contact, for *on*. In both cases this geometric specification could be represented according to the qualitative geometry developed by Cohn and colleagues, which is well suited to capture the coarse grained geometry of containment and support.

An important question raised by the results of the experiments concerns how these two components relate to each other. In the introduction we emphasised the close correlation between geometry and function. Thus, in general the coarse grained geometry of enclosure or contact is associated with situations where there is location control through fcontainment or fsupport. Nevertheless, the results from Expt. 1 also suggest that function and geometry may affect our confidence in containment to

[3] In many respects this notion is similar to Michotte's (1963) notion of direct perception of causality when viewing dynamic interactions between objects.

different degrees under different circumstances. Thus, it was clear that the confidence in location control judgements played an important role in predicting confidence in *in* judgements in those situations where enclosure was weak (i.e. where the ball was at or above the rim of the bowl). However, when enclosure was strong (in terms of Cohn's geometry) the different degrees of control, as indexed by the independent dynamic judgements, seemed to have much less influence on confidence. One explanation for the dominance of geometric information when enclosure is strong is that geometry may be a primary perceptual indicator of location control under those circumstances. In other words, prototypical enclosure may strongly indicate location control. However, it could also be that the geometry in these clear cases dominates our judgements of inness irrespective of alternative information about location control.

Some examples of the use of *in* suggest that the second account is the correct one. For example, it is quite natural to describe a plane as being in a cloud when there is topological enclosure (i.e. when it is completely surrounded by the cloud), even though we would not judge the cloud to control the location of the plane. However, if by some meteorological accident the plane happened to be within the bounds of a bowl-shaped cloud and hence only geometrically enclosed (see Fig. 2b), then the description would become inappropriate. So it may be that prototypical enclosure licenses the use of *in* even when there is no location control. However, by the same token the experiments reported here indicate that there can be strong intuitions of containment in the absence of prototypical enclosure. Together these two observations point to a hybrid concept of containment: situations where there is a clear geometry of enclosure indicate containment irrespective of control, but for situations where the geometry is marginal we require evidence of location control before perceiving containment.

The hybrid account can accommodate these special uses of *in* where there is prototypical enclosure in the absence of location control. However, there are also cases where we naturally use *in* that might seem to actually contradict the control relationship. These typically involve situations with clothing or jewellery in which there is tight enclosure of the human body or one of its parts.[4] For example, we can say of a foot that it is **in** a shoe, but we can also say of a shoe that it is **on** a foot. So it appears that the shoe is supposed to control the location of the foot through fcontainment and, at the same time, the foot is supposed to control the location of the shoe through fsupport. We suggest that this ambiguity arises because with tight enclosure foot and shoe mutually constrain each other's location. If the shoe is moved the foot will move with it,[5] but also if you move your foot the shoe will move with the foot. The problem is one of perspective. When concentrating on the way clothing constrains the body part *in* is appropriate, but when concentrating on

[4] Interestingly, the Oxford English Dictionary reserves a special sense of *in* for these uses.

[5] This kind of location control is often highlighted in fictional situations, as with Dorothy and the red shoes that took her up the yellow brick road in the Wizard of Oz, or, more recently, the automated trousers leading their wearer into mischief in Wallace and Grommett's famous cartoon 'The Wrong Trousers'.

what supports the clothing then *on* is appropriate. A hybrid account will accommodate such cases just so long as the enclosure is prototypical (e.g., it is strange to say 'the man has his head **in** his hat' but we can say 'the man has his hat **on** his head).

A further issue in any analysis of spatial prepositions is that of cross-linguistic variation. In relation to this account, it is clear that core concepts such as containment and support can be expressed in different ways both within and across different languages. For example, in English there are other prepositions expressing containment, such as *within* and *inside*, which impose subtle additional constraints on the relation (e.g. *inside* imposes a special geometric condition on the nature of the relatum – that it have interior surfaces which surround the referent). Other languages carve up the conceptual space around containment and support in different ways again. For example, Bowerman (1996b) illustrates four quite different semantic classifications for the situations of 'a cup on a table', 'an apple in a bowl' and ' a handle on a door' in English, Finnish, Dutch and Spanish. We suspect that these different systems reflect refinements in the geometric classification of forms of *enclosure* or forms of *contact* rather than differences in the basic location control relations. One of the virtues of a hybrid account may be in clarifying this range of semantic options across different languages.

A final issue that needs to be considered is that of extended uses of the prepositions. Both *in* and *on* seem to lend themselves to uses which clearly go beyond the purely spatial. For example, you can be *in* a mood (e.g. a temper, depression, an alcoholic haze etc.) or you can be *on* financial support (e.g. a widow's pension, social security etc.). A virtue of the hybrid account is that it may give greater insight into the origin of some of these extensions. In many cases, as in the examples above, the functional component of the hybrid account proposed here seems much more appropriate as the origin of the extended meaning than the geometric component (see Garrod and Sanford, 1989).

7. Summary and conclusions

We started out this paper by posing the question of whether the representation of the meaning of the locatives *in* and *on* was primarily geometric, primarily functional or a mixture of the two. The rationale for the functional hypothesis came from the idea that there might be functional geometric concepts such as fcontainment and fsupport which capture physically informative spatial relationships between objects in the world. The experiments which followed tested the functional geometric account against a more straightforward geometric one.

This led to the conclusion that functional information, such as that associated with location control between objects, does affect a viewer's confidence in descriptions containing *in* and *on.* However, it was also found that the degree of this effect was modulated by the extent to which the geometry in the scenes was prototypical. As a consequence we argued for a hybrid account of the representation incorporating both geometrical and functional information.

This account offers an explanation for the indeterminacy issue raised at the outset. We are proposing that spatial descriptions per se do not specify spatial relations of a purely geometric kind, yet they do denote intuitively simple and well-defined conceptual relations. In accordance with Landau and Jackendoff (1993), we take the view that there are only a few such relations *between* objects that have any real significance. Whereas the precise position of eyes relative to nose and mouth may be crucial in discriminating between faces, precisely where a pear lies relative to a bowl is not so crucial for determining whether it is *in* the bowl or not.

Acknowledgements

We would like to acknowledge the following colleagues for helpful comments on an earlier version of this paper: Steven Frisson, Martin Pickering, Philippe Schyns and Roger von Gompel. We would also like to thank Barbara Landau and two other anonymous reviewers for extremely helpful comments on an earlier draft.

References

Allen, J. F. (1983). Maintaining knowledge about temporal intervals. *CACM*, *26* (11), 832–843.

Aurnague, M. (1995). Orientation in French spatial expressions: formal representations and inferences. *Journal of Semantics*, *12* (3), 239–268.

Bennett, D. C. (1975). *Spatial and Temporal Uses of English Prepositions: An Essay in Stratificational Semantics*, London: Longman.

Bowerman, M. (1996). Learning how to structure for language: a crosslinguistic perspective. In P. Bloom, M. A. Peterson, L. Nadel & M. Garrett, *Language and Space*, (pp. 385–436). Cambridge, MA: MIT Press.

Bowerman, M. (1996). The origins of children's spatial semantic categories: cognitive versus linguistic determinants. In J. J. Gumperz & S. C. Levinson, *Rethinking Linguistic Relativity*, (pp. 145–176). Cambridge: Cambridge University Press.

Cohn, A. G. (1996). *Calculi for Qualitative Spatial Reasoning, Proceedings of AISMC-3, LNCS*, Berlin: Springer.

Cohn, A. G., Bennett, B., Gooday, J., & Gotts, N. M. (1997). Qualitative spatial representation and reasoning with the region connection calculus. *Geoinformatica*, *1* (3), 1–42.

Cooper, G. S. (1968). *A Semantic Analysis of English Locative Prepositions, Bolt, Beranek and Newman Report No: 1587*, Springfield, VA: Clearing House for Federal Scientific and Technical Information.

Coventry, K. R., Carmichael, R., & Garrod, S. C. (1994). Spatial prepositions, object specific function and task requirements. *Journal of Semantics*, *11* (4), 289–311.

Crangle, C., & Suppes, P. (1989). Geometric Semantics for Spatial Prepositions. *Midwest Studies in Philosophy*, *14*, 399–421.

Garrod, S. C., & Sanford, A. J. (1989). Discourse models as interfaces between language and the spatial world. *Journal of Semantics*, *6*, 147–160.

Herskovits, A. (1986). *Language and Spatial Cognition*, Cambridge: Cambridge University Press.

Landau, B., & Jackendoff, R. (1993). 'What' and 'where' in spatial language and cognition. *Behavioural and Brain Sciences*, *16* (2), 217–265.

Leech, G. N. (1969). *Towards a Semantic Description of English*, London: Longmans.

Michotte, A. (1963). Translated from La Perception de la causalité (1946). *The Perception of Causality*, London: Methuen.

Miller, G. A., & Johnson-Laird, P. N. (1976). *Language and Perception*, Cambridge: Cambridge University Press.

Suppes, P. (1991). The principle of invariance with spatial reference to perception. In J. Doignin & J. Falmagne, *Mathematical Psychology: Current Developments*, (pp. 35–53). New York: Springer.

Talmy, L. (1988). Force dynamics in language and cognition. *Cognitive Science*, *12*, 49–100.

Vandeloise, C. (1991). Translated by A.R.K. Bosch. *Spatial Prepositions: A Case Study from French*, Chicago/London: The University of Chicago Press.