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Influences of Form and Function on Spatial Relations

ESTABLISHING FUNCTIONAL AND GEOMETRIC INFLUENCES ON PROJECTIVE PREPOSITIONS IN SWEDISH

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The present work is concerned with projective prepositions, which express the relation between two objects by referring to a direction in three-dimensional space. The projective prepositions have been regarded as expressing simple schematic relations of a geometric nature. A theory of the apprehension of projective relations can account for their meanings when they express strictly geometric relations. However, many studies have shown that the appropriateness of the prepositions also depends on the functional relation between the objects and that a number of functional factors influence the comprehension of English prepositions. This experimental study investigates if the acceptability of the Swedish prepositions *över*, *under*, *ovanför* and *nedanför* are influenced by functional factors as well, and whether acceptability judgments about *över* and *under* are more sensitive to functional influences than judgments about *ovanför* and *nedanför*, as has been shown for the corresponding English prepositions *over* and *under*, and *above* and *below*, respectively. It also investigates how the shapes and the parts of the related objects influence their functional interaction, and how the acceptability of the prepositions is in consequence influenced by the shapes of the objects. It was found that the theory of apprehension can indeed account for the acceptability of the prepositions when the relation between the objects is strictly geometric. It was further found that acceptability judgments about them are influenced by functional factors in a similar manner to the corresponding English prepositions when the objects are functionally related, although judgments about *under* and *nedanför* are not differentially influenced by these factors. Furthermore, the shapes and the parts of both of the related objects influence acceptability judgments about the prepositions in predictable manners. An extension of the theory of apprehension is suggested which can account for the functional influences indicated in the present study.

Magister Thesis in General Linguistics
Autumn 2006
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1. Introduction

1.1. THE FRAMEWORK FOR THE PRESENT WORK

Spatial language and spatial expressions have received much attention in the linguistic and psycholinguistic literature for a number of reasons. Spatial expressions are concerned with spatial relations which are objectively measurable properties of space. Therefore, the domain of spatial language serves well for semantic investigations as spatial terms can be defined with respect to such measurable properties (Regier, 1996). Also, although subject to much cross-linguistic variation, a common view is that spatial language is based on non-linguistic representations of spatial relations. As such, spatial language is considered to be well suited for investigating the connection between language and non-linguistic cognition and is believed to be able to provide an insight into spatial cognition (Hayward & Tarr, 1995; Jackendoff & Landau, 1993; Landau, 1996; Logan & Sadler, 1996; Miller & Johnson-Laird, 1976; Munnich, Landau & Dosher, 2001; Regier, 1996; Regier & Carlson, 2001); (however, see Bowerman (1996; 2000) and Bowerman & Choi (2003) for a different view). Furthermore, the domain of space is considered fundamental in non-linguistic cognition and is seen as a privileged area within language as it is believed to serve as a fundamental conceptual structuring device (Herskovits, 1986; Miller & Johnson-Laird, 1976; Regier, 1996; Talmy, 1983). As spatial expressions are made up by a closed class of words, the linguistic encoding of the conceptual domain of space is limited by the spatial properties those words express. Thus our linguistic conceptualization of space is limited by the spatial properties encoded by language. Also, the fact that spatial expressions are often used metaphorically in non-spatial domains indicates that spatial thinking serves as a structuring tool of other conceptual domains as well.

The present work is concerned with the closed class of words that express relations between two objects in space, the locative prepositions, and examines what properties such prepositions express. In section 2.1., various types of locative prepositions are defined and the nature of the relations they express is discussed. The work is primarily concerned with a subclass of locative prepositions, the projective prepositions, which express the relation between two objects by referring to a direction in three-dimensional space. The characteristics of projective prepositions are further explored in section 2.1. The traditional view of projective prepositions, presented in section 2.2., is that they express simple schematic relations of a geometric nature. Theories of the apprehension of projective relations that grounds the meaning of projective prepositions in perceptual processes are presented in section 2.3. The theories assume that judgments about whether or not a specific projective is applicable to a spatial relation depend on a number of geometric factors.

However, a number of empirical studies have shown that the comprehension of spatial expressions involving projective prepositions in English also depends on the functional relation between the objects. Functional relations, in turn, largely depend on knowledge about the functions of the objects, which is determined to a great extent by the shape and the parts of those objects. Such functional influences on the comprehension of projective prepositions are discussed in section 2.4. The section also deals with how the functions objects afford depend on characteristics of the shape and the parts of those objects. These empirical results show that the apprehension of projective relations not only depends on geometric factors but also on functional factors.

The meanings of projectives thus depend on multiple source of information of both a geometric and functional nature. In section 2.5., two theories of the meanings of projectives that take both geometric and functional factors into account are presented. The first is an extension of the theory of the apprehension of projective relations that can account for some of the functional influences. The second assumes that judgments about the applicability of a projective preposition depend on the situation-specific integration and weighting of geometric and functional factors, and that these factors depend on distinct processes.

1.2. THE PURPOSE OF THE PRESENT WORK

The main purpose of the present work is to investigate experimentally whether the appropriateness of Swedish projective prepositions is influenced by functional factors as well. A previous study has shown that Swedish projectives are influenced by function in a part of the apprehension process (Hörberg, 2004), which is discussed in section 2.4.3. Thus, it is likely that Swedish prepositions are influenced in other ways as well, as has been shown for English prepositions. The rationale of the experiment is to assess the influences of functional factors by holding geometric factors constant while manipulating the functional relation between the objects. The assumption is that acceptability judgments of Swedish projectives are influenced by the geometric factors of importance according to the theories of apprehension, presented in section 2.3, when the relation designated by the preposition is strictly geometric. However, when there are also functional aspects to the relation, functional influences are predicted to interfere with geometric factors in systematic ways.

Another purpose of the experiment is to further explore the influence of the shapes of the spatially related objects. If acceptability judgments about projective prepositions depend on the functional interaction between the objects, and the functional interaction is constrained by the shapes and the parts of those objects, acceptability judgments about projectives should also depend on the shapes of the objects. Such influences are investigated by manipulating the position of the functional parts of the objects and the precision required for the objects to interact, which depend on the size of the functional parts.

English vertical projectives have been shown to be influenced by functional factors to varying degrees, as discussed in section 2.4.4. A final purpose of the experiment is to investigate if the corresponding Swedish projectives are differentially influenced in a similar manner.

The experimental design is presented in section 3.1 in which the purpose and rationale of the experiment is further discussed. Also, the variables of the experiment are operationally defined in this section and the predictions associated with them are described. The results of the experiment are presented in chapter 4. Section 4.1. deals with the results of the geometric manipulations. With respect to these results, the influences of the functional manipulations are presented in sections 4.2. and 4.3. In section 5.1., the predictions of the experiment are discussed and the evidence provided by the results for geometric and functional influences is reviewed. Section 5.2. is concerned with how these influences differ between the Swedish prepositions included in the experiment. Shortcomings of the experimental design are outlined in section 5.3. Finally, a further extension of the theories of the apprehension of spatial relations is presented in section 5.4. This extension can account for the functional influences apparent from the results of the present study. It can also account for functional influences in situations in which geometric factors are held constant, and does not rest upon the assumption that functional and geometric factors depend on distinct processes.

2. Theoretical background

2.1. LOCATIVE PREPOSITIONS

2.1.1. A classification of locative prepositions

In traditional grammar, prepositions make up a closed class of words, usually divided into grammatical and local prepositions. Whereas grammatical prepositions do not carry much meaning and mainly function as syntactic markers, local prepositions have a temporal or spatial meaning.

Following Coventry & Garrod (2004), spatial prepositions can be further divided between directional prepositions on the one hand and locative or relational on the other. Directional prepositions express a direction as in *He went forward*, or a direction in which an object is located as in *The house is to the north*, or a change in position, as in *He drove across the bridge.* Locative prepositions express the location of one object by relating it to one or two others. For example, in *The apple is in the bowl* the location of the apple is established with respect to the bowl.

2.1.2. Types of locative prepositions

Locative prepositions can be further divided between *topological* on the one hand and *projective* or *dimensional* (Coventry & Garrod, 2005; Grabowski & Miller, 2000; Grabowski & Weiss, 1996) on the other. Topological prepositions express spatial relations of a topological nature and refer to relations concerned with topological concepts such as inclusion and contiguity on the one hand and proximity on the other. *Simple* topological prepositions express relations of the latter form, such as *in* and *on*, whereas *proximity* prepositions express relations of the former, such as *near* and *far.*

Projective prepositions, the primary concern of the present work, express relations in the dimensional structure of space by specifying a direction in three-dimensional space in which an object is located with respect to a reference location or object (Coventry & Garrod, 2005; Garrod, Ferrier & Campbell, 1999; Grabowski & Miller, 2000; Grabowski & Weiss, 1996; Hörberg, 2004; Jackendoff & Landau, 1993) For example, in *the sun is above the house* the projective preposition *above* expresses the direction in which the sun is positioned with respect to the house.

A few locative expressions have a meaning of both a topological and dimensional nature. For example, the meaning of the composite preposition *in the back of* depends on both topological and dimensional properties of the reference object (Grabowski & Weiss, 1996). In the present work, such complex prepositions are excluded, and only prepositions concerned with purely dimensional relations are considered.

2.1.3. The syntactic structure of locative expressions

In English and Swedish, locative expressions are constructed using a complement or adjunct prepositional phrase. In its simplest form, the PP functions as an attributive adjunct of a nominal phrase:

1. [$_{NP}$ [$_{NP}$ *the book*] [$_{PP}$ *on the table*]]

The PP can also function as a predicative complement in a sentence:

2. [$_{S}$ [$_{NP}$ *The book*] *is* [$_{PP}$ *on the table*]]]

Or as the complement of a quantified expression:

3. [$_{S}$ *There are* [$_{NP}$ *some books*] [$_{PP}$ *on the table*]]

As an adverbial adjunct:

4. [$_{S}$ [$_{NP}$ *The book*] *is lying at home* [$_{PP}$ *on the table*]]

Or, finally, as an adverbial complement, in accordance with the semantic and syntactic restrictions put on the arguments by the verb:

5. [$_{S}$ [$_{NP}$ *She*] *put* [$_{NP}$ *the book*] [$_{PP}$ *on the table*]]

In sentence 2 to 5, the clause can be regarded as the first argument of the preposition (Coventry & Garrod, 2005; Herskovits, 1986; Miller & Johnson-Laird, 1976). In such constructions, it is the event expressed by the clause that is to be located with respect some reference.

In the construction types 4 and 5, the verb can influence the meaning of the locative expression. In sentence 5, it is not the location of the book that is to be established in relation to the preposition. Rather, the verb *put* demands an argument with the thematic role of goal. The PP satisfies this condition, and in this construction type it refers to the end place of the trajectory of the action expressed by the verb (Coventry & Garrod, 2005; Herskovits, 1986). Thus the restrictions of the verb influence the meaning of the preposition.

The verb can also affect the meaning of the locative expressions in sentences like 4. Following Talmy (1985), languages like English or Swedish are satellite-framing languages.[1] Such languages express the manner and cause of a motion event in the verb root whereas the path of the event is expressed in *satellites*, particles or affixes other than inflections, auxiliaries or predicate arguments that are part of the verb root. For instance, in *The plane flew over the house*, the manner of movement is expressed by the verb *flew*, whereas the satellite *over* expresses the path. Talmy (1985) suggests that satellites in general should be distinguished from prepositions on grammatical, syntactical and phonological grounds. However, a clear distinction in English is sometimes hard to make. For instance, the form *past*, as in *He drove past the store*, has properties of both prepositions and satellites (Talmy, 1985). Thus a clear distinction between verb particle and preposition is not that easy to make. However, it is clear that the meaning of a spatial expression in constructions like 4 often is affected by the verb in the sentence (Coventry & Garrod, 2005; Herskovits, 1986) and the relation expressed by a preposition can be interpreted with a static or dynamic sense depending on the accompanying verb. For example, *over* expresses different senses in the following sentences:

The sun shines over the house.
The plane flew over the house.

In the first case, *over* refers to a spatial region relative to the house, an *above* sense in the terminology of Lakoff (1987). In the second, *over* also expresses information about a path of motion within that spatial region, an *above-across* sense according to Lakoff (1987). Either the meaning of *over* is polysemous (Lakoff, 1987), or situation-specific and

[1] Other languages, such as Spanish, are classified as verb-framing languages, expressing the notion of path in the verb root whereas the manner of motion can be expressed with a complement participle, not being part of the actual verb root.

ultimately determined by context (Coventry, 1998, 2003; Coventry & Garrod, 2004, 2005; Garrod & Sanford, 1989) as discussed in section 2.5.2. However, the present work is only concerned with locative expressions with a static sense. The influence of verb meaning is avoided by only investigating predicative constructions with a copula having a purely grammatical function, as in 2 above.

2.1.4. The nature of locative relations

Spatial prepositions are concerned with relative spatial relations; they express relations relative to a reference location or object (Miller & Johnson-Laird, 1976; Talmy, 1983). *Basic spatial relations* specify the location of an object with respect to some reference determined by context, usually the viewpoint of the speaker or the viewer (Logan, 1995; Logan & Sadler, 1996). As the reference is implicit, they take only the object to be located as argument. For example, in the relation expressed by *here* in *The book is here*, *here* refers to a location given by context. Locative relations, on the other hand, establish the location of an object in relation to one or two other objects or locations, which function as the relatum or relata of the relation (Herskovits, 1986; Logan, 1995; Logan & Sadler, 1996; Miller & Johnson-Laird, 1976). As such locative relations take two or three arguments, the first being the object to be located and the others the object or objects of reference. For example, *the plain* functions as the reference location in the relation expressed in *the cloud above the plain*, whereas *the barn* and *the tree* function as the reference objects in the relation expressed in *the bike between the barn and the tree*.

The spatial relations expressed by prepositions are thus relations for which the position of some object or location is determined with respect to one or two reference locations or objects, either implicitly or explicitly. The present work is only concerned with locative relations that specify the location of an object with reference to a single other. The object of reference of such a relation is called *reference object* whereas the object to be located is called *located object* (Coventry & Garrod, 2005; Hörberg, 2004; Logan, 1995; Logan & Sadler, 1996). Other terms appear in the literature, such as *secondary* and *primary object* (Talmy, 1983), *reference* and *located entity* (Herskovits, 1986), *reference object* and *figure* (Jackendoff & Landau, 1993), *ground* and *figure* (Herskovits, 1998; Levinson, 1996; Talmy, 1983, 1985), *target* and *landmark* (Miller & Johnson-Laird, 1976) or *trajectory* and *landmark* (Lakoff, 1987), the latter usually referring to relations involving movement. In this study, the terms *reference object* and *located object* will be used. The located object in a spatial relation is the object of focus whose spatial position is to be established. This is done with respect to the location of the reference object, which is a backgrounded object whose location is already known or assumed to be known (Herskovits, 1986; Hörberg, 2004; Jackendoff & Landau, 1993; Miller & Johnson-Laird, 1976; Talmy, 1983). A spatial relation expressed by a preposition can thus be seen as a *spatial region* defined with respect to the reference object within which the located object is positioned (Hörberg, 2004; Jackendoff, 1996; Miller & Johnson-Laird, 1976). Canonical reference objects tend to be stable and large, therefore serving as good spatial references, whereas located objects tend to be more movable and smaller. This asymmetry between the objects is reflected in the syntactic encoding of the relations in spatial expressions as the first argument of the preposition refers to the movable located object whereas the second refers to the more stable reference object. Furthermore, this asymmetry has been assumed to reflect properties of non-lingustic spatial cognition (Jackendoff & Landau, 1993).

2.1.5. Projective prepositions and frames of reference

Objects extend in space along three dimensional axes, as illustrated in figure 1. The axes intersect at the centre of the object, extending in each dimension. As mentioned in section 2.1.2, projective prepositions expresses a direction in three-dimensional space in which the located object is positioned with respect to the reference object. It is usually assumed, explicitly or implicitly, that these directions are derived from the axial structure of the reference object (Herskovits, 1986; Hörberg, 2004; Jackendoff & Landau, 1993). The axes constitute six half axes, or *base axes* (Herskovits, 1986), each originating at the centre of the reference object and extending in a direction of its own. Thus each projective preposition refers to a spatial region defined with respect to one of the base axes, depending on its direction. For example, *above* would refer to a spatial region around the axis labeled *a* in figure 1, whereas *in front of* would refer to a region adjacent to the axis labeled *b*. However, in order to assign prepositions to the base axes, the directions of the axes has to be established. Furthermore, many objects, such as spheres, lack inherent dimensional axes and in order to use them as reference objects an axial structure has to be imposed on them.

This is done with respect to a perspective system (Levelt, 1996; Miller & Johnson-Laird, 1976) or a frame of reference (Carlson-Radvansky & Irwin, 1994; Carlson-Radvansky & Jiang, 1998; Carlson-Radvansky & Logan, 1997; Hörberg, 2004; Levinson, 1996; Logan, 1995). A frame of reference is thus the kind of perspective in terms of a coordinate system (Levinson, 1996) that is adopted in the process of imposing or orienting and directing an axial structure on the reference object. Three different types of reference frames exist; the *relative*, the *intrinsic* and the *absolute* frame of reference.

When adopting the relative frame of reference, an axial structure is either imposed or oriented and directed with respect to a coordinate system based on the point-of-view of the viewer and/or speaker. This can be done in three ways. In Indo-European languages like English and Swedish, the axes corresponding to the vertical and transversal planes are oriented analogous to the orientation of the viewer, whereas the orientation of the axis corresponding to the sagittal plane is reversed with respect to viewer (Herskovits, 1986; Levelt, 1996; Levinson, 1996). That is, the front of the reference object is the side facing the viewer whereas the other sides of the object correspond to the sides of the viewer. In other languages, for example Hausa, all of the axes are oriented analogous to the orientation of the viewer, so that the back of the object is facing the viewer (Herskovits, 1986; Levinson, 1996; Regier, 1996; Talmy, 1983).[2] In yet other languages, such as Tamil, the orientation of all horizontal axes is reversed, so that the viewer is facing the front of the object but the distinction between left and right is opposite that of the viewer (Levinson, 1996).

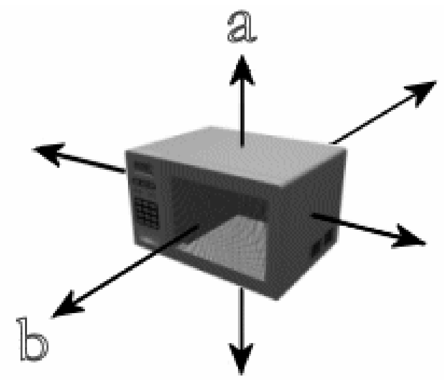


Figure 1. Objects extend in space along three dimensional axes. *Above* refers to the spatial region adjacent to axis *a*, whereas *in front of* refers to the spatial region close to axis *b*.

[2] Herskovits (1986) refers to the former strategy as the *encounter situation* and the latter as the *coincidence situation*.

The intrinsic frame of reference is the inherent coordinate system of the reference object itself, which is determined by inherent features of the object. For example, base axis *b* in figure 1 corresponds to the preposition *in front of* because the axis is directed towards the side of the oven which is regarded as its front, due to the fact that its opening is located at that side. As such, the intrinsic frame of reference is independent of a point-of-view, but requires a reference object with intrinsic sides.

When the absolute frame of reference is adopted, the axial structure is either imposed or oriented and directed with respect to a fixed coordinate system of bearings as the cardinal directions of the compass or one that is based on prominent features of the global or local environment. For instance, the system can be based on the fixed direction provided by gravity or derived from important topographical features of the environment such as a hillside. The absolute frame of reference is thus independent of both an inherent coordinate system and a point-of-view, but require that the language users are aware of the orientation of the bearings at all times (Coventry & Garrod, 2005; Levinson, 1996).

Thus the comprehension and use of projectives presupposes a choice of perspective system or frame of reference, a coordinate system based on the kind of perspective adopted. In some languages, only one or two of the systems are used, whereas English and Swedish use all three of them (Coventry & Garrod, 2005; Levelt, 1996; Levinson, 1996).[3]

To illustrate this point, imagine viewing a plane diving towards the ground at a perfect vertical angle while tilting your head 90 degrees to the right. The view would be similar to the illustration in figure 2. In such a situation, the three frames of reference are in conflict. That is, the assignment of directions to the half axes varies, depending on the frame of reference adopted. In the perspective of the viewer, the half axis labelled *a* in the figure is the *up* axis. On the other hand, the *b* half axis is the *up* axis with respect to the intrinsic top of the plane. Finally, the *c* axis can be assigned the *up* direction, as it is opposite to the direction of the force of gravity. That is, The *up* direction is assigned to axis *a* according to the relative frame of reference, to axis *b* in accordance with intrinsic frame of reference or to axis *c* with respect to the absolute frame of reference.

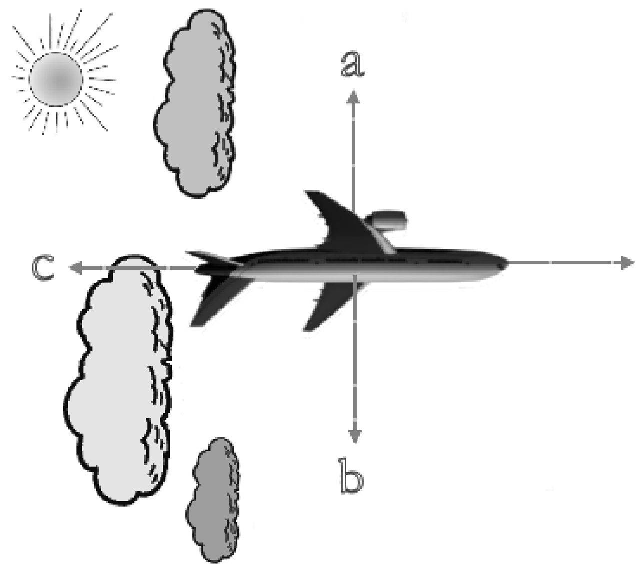


Figure 2. The assignment of directions to the base axes depend on the frame of reference adopted. The *up* direction is assigned to axis *a* according to the *relative* frame of reference, to axis *b* according to *intrinsic* frame of reference or to axis *c* according to the *absolute* frame of reference.

[3] For instance, the language Guugu Yimithirr uses only the absolute system, Mopan only the intrinsic system, whereas Tzetzal uses both the absolute and intrinsic system but not the relative (Levelt 1996; Levinson 1996).

2.2. TRADITIONAL VIEWS ON THE MEANING OF LOCATIVE PREPOSITIONS

2.2.1. Minimally specified geometric definitions

Traditionally, locative prepositions have been seen as directly referring to geometrical relations of a topological or dimensional nature and their meanings have been regarded as simple geometric descriptions of such relations (see, e.g., Coventry & Garrod, 2004; Herskovits, 1986; Jackendoff & Landau, 1993; Miller & Johnson-Laird, 1976). Therefore, minimally specified definitions of their meanings have been suggested. For instance, Miller & Johnson-Laird (1976) suggests the following definition for *in*:

IN (x, y): [PART (x, z) & INCL(z, y)]

The predicates PART (x, y) and INCL (x, y) are regarded as perceptual routines where PART (x, z) defines z as a part of x and INCL (z, y) establishes if z is enclosed by y. Roughly then, x can be said to be *in* y if some part or the whole of x is perceived as being enclosed by y. On this account, a locative preposition is regarded as a function that establishes a search domain for a located object with respect to a reference object within some mental spatial representation (Herskovits, 1986; Jackendoff, 1993; Miller & Johnson-Laird, 1976). The search is guided by perceptual routines, as PART (x, y) and INCL (x, y) for *in*. Thus the meaning of a locative preposition is a basic geometric description based on simple topological or dimensional concepts, such as *enclosure*, *contiguity* or *vertical alignment*, which identify a spatial region with respect to a reference object within a spatial representation of space.

2.2.2. Schematization

Minimally specified accounts of the meanings of locative prepositions are consistent with the view that locative prepositions pick out certain geometric aspects of a spatial relation while disregarding others, a process known as *schematization* (Carlson-Radvansky, Covey & Lattanzi, 1999; Carlson, 2000; Herskovits, 1998; Landau, 1996; Talmy, 1983, 1988). Schematization involves an *idealization* of certain key aspects of a spatial scene into primitive geometric components while other more fine-grained distinctions of that scene are abstracted away. Thus fine-grained distinctions of the shape and size of the spatially related objects as well as distinctions in the distance between them are largely ignored by locative prepositions according to this view (Jackendoff & Landau, 1993; Talmy, 1983). According to Talmy (1983), located objects are often schematized to a single point, or in some instances to a two-dimensional line or plane whereas the restrictions on the shape of the reference object are somewhat stronger. For example, the preposition *in* demands that the reference object has an interior whereas *on* requires a planar reference object. However, none of the prepositions make any restrictions on the shape of the located object. Also, idealized parts of an object are often selected to represent the object as a whole (Herskovits, 1998). For instance, in the expression *the cat under the table*, the top of the table represents the whole table.

Also, the differences of the geometric aspects picked out by various prepositions are not fine-grained. Each preposition differs from others by idealizing a different set of geometric primitives, while abstracting away aspects picked out by other prepositions (Talmy, 1983). For example, in the sentence *The tablecloth is laying over the table* the fact that the tablecloth is covering the table is idealized, whereas the covering aspect is irrelevant in *The tablecloth is laying on the table* and is thus abstracted away. A vast number of fine-grained spatial configurations fit the schematic representation of each preposition.

Furthermore, the closed-class inventory of spatial prepositions within a language is limited.[4] An inventory of spatial prepositions thus represents an infinite number of fine-grained spatial configurations with a small set of schematic representations that pick out different key aspects of those configurations according to this view (Jackendoff & Landau, 1993; Talmy, 1983).

Considering projective prepositions, the reference object is schematized to an axial structure and the located object to a point. The point is usually, implicitly or explicitly, assumed to coincide with the centre-of-mass of the located object (Carlson-Radvansky et al., 1999; Jackendoff & Landau, 1993; Landau, 1996).[5] Finally, according to Miller & Johnson-Laird (1976) the selection of frame of reference is trivial. If the reference object lacks inherent dimensional axes and an axial structure is to be imposed on it, the deictic frame of reference has to be used. For reference objects with inherent dimensional axes, the intrinsic reference frame is dominant and always used, unless the speaker explicitly exhorts application of the deictic reference frame by adding "from my point of view" or "as I am looking at it" (Miller & Johnson-Laird, 1976).

2.3. THEORIES OF THE APPREHENSION OF PROJECTIVE RELATIONS

As discussed in section 2.1.4., locative prepositions can be seen as defining a spatial region within which a located object is positioned with respect to a reference object. Such a spatial region can be regarded as a search domain within a mental spatial representation (Herskovits, 1986; Jackendoff & Landau, 1993; Miller & Johnson-Laird, 1976); (see section 2.2.1.). Such accounts of the meaning of locative prepositions presuppose some kind of mapping between the conceptual representation of the spatial expression and some mental spatial representation of the real-world spatial relation designated by that expression. For example, the truth of a statement involving a spatial expression such as *The painting is hanging above the fire place* can only be evaluated with respect to the spatial relation between the painting and the fire place, as perceived by the hearer. Thus, although the hearer can comprehend the statement by conceptualizing it, he or she has to evaluate that conceptualization against her perception of the relation between the painting and fire place, in order to determine whether or not the statement is true. Much work has been devoted to such mapping between conceptual and spatial representations (Carlson-Radvansky & Logan, 1997; Garrod & Sanford, 1989; Hayward & Tarr, 1995; Jackendoff & Landau, 1993; Logan, 1995; Logan & Sadler, 1996; Munnich et al., 2001; Regier, 1996; Regier & Carlson, 2001).

2.3.1. The conceptual and the spatial system

Jackendoff (1996) has a modular view on our cognitive apparatus and argues that different formats of information, for example conceptual and phonological information, are encoded by separate cognitive modules or systems. *The conceptual system* encodes linguistic meaning independently of a specific language by using universal elements of *ontological category features* (Jackendoff, 1993), such as the notion of path or place, that serve as primitives that make up different conceptualizations of a propositional format. *The spatial system*, on the other hand, encodes three-dimensional spatial representations of objects and visual scenes as wholes, independently of a point-of-view, by incorporating information from different sensory modalities (Jackendoff, 1996).[6] Some ontological

[4] Jackendoff & Landau (1993) note that English has about 80 to 100 prepositions, many of them being non-spatial. Considering that the language contains tens of thousands of nouns, the inventory of spatial prepositions is limited indeed.

[5] Though Herkovits (1998) states that the shape of the objects is of importance when they are near each other.

[6] Jackendoff (1996) labels the conceptual system *conceptual structure* (CS) and the spatial system *spatial representation* (SR).

category features, such as the notion of place and path, are shared between the systems. System-specific information about more specific categories, that has to be learned, is matched through lexical items. On this view, the lexical entry of a word is a matching of its phonological structure with its morphological and syntactic properties, the ontological category features associated with the meaning of that word, and some schematic spatial representation of the prototypical referent of the word. A concept is strictly the matching between the category features of the conceptual system and the spatial representation of the spatial system. Comprehension and production of spatial expressions thus presuppose a mapping between the conceptual and spatial systems and a projective concept is the matching between a projective predicate in the conceptual system and a representation of a spatial relation in the spatial system.

2.3.2. The perceptual process of apprehending a projective relation

As mentioned in section 2.1.5., projective prepositions presuppose a choice of frame of reference which guides the process of imposing or orienting and directing an axial structure on the reference object. Furthermore, the traditional view is that projective prepositions schematize the reference object to such an axial structure and the located object to a point (see section 2.2.2.). A common assumption is that the reference frame itself is the axial structure which either is imposed on or extracted from the reference object and that the assignment of projective terms is dependent on the direction of the base axes of this structure.[7] On this view, it is the axial structure of the reference frame that guides the mapping between the conceptual and spatial system by assigning projective predicates to each of the base axes of the axial structure. Jackendoff (1996) suggests that such axial structures are a component of spatial representations and, as such, they reside in the spatial system and are set via perceptual processes (Carlson, 2000; Coventry & Garrod, 2004).

Logan (1995) and Logan & Sadler (1996) present a theory of how such perceptual processes operate, based on theories of visual spatial attention and theories of linguistic encoding of spatial relations. The theory is thus a theory of the apprehension of projective relations. In essence, it involves four different processes; The processes *spatial indexing* and *reference frame adjustment* account for how correspondences between conceptual and spatial representations of spatial relations are established, whereas *spatial template alignment* and *goodness-of-fit computation* provide an account of establishing how good of an example a specific spatial relation is of given a spatial concept.

In order to account for different task demands, the theory assumes that these processes and the representations involved therein can be ordered and applied in a flexible manner. The task at hand might be to identify the location of an object (as when asked *where is the book?*), identify an object in an already known projective relation (as when asked *is that Paul next to Tom?*), or to verify whether a specific relation between two objects applies in a scene (as when the truth of a sentence like *Paul is standing behind Tom* is to be evaluated). For example, when the task at hand is to identify the location of an object, that object has to be identified in the spatial representation, a suitable reference object has to be identified and a suitable spatial concept has to be selected depending on the relation between the objects. When, on the other hand, the task is to identify an object in an already known relation, the reference object of that relation has to be identified, the spatial region corresponding to the relation has to be established, and the object located within the region has to be identified.

[7] This contrasts with the views of Levinson (1996), according to whom frames of reference are coordinate systems that operate on several levels of mental representations since frames of reference are involved in non-linguistic tasks as well. On this view then, frames of reference might guide the process of imposing an axial structure on the reference object but are separate from such axial structures.

2.3.3. Spatial indexing and reference frame adjustment

Spatial indexing is the process by which the arguments of a conceptual representation of a spatial expression are matched with the appropriate objects in a spatial representation. Spatial indexing determines the location of an object in the spatial representation by identifying it as an argument. It is thus all that is required for establishing basic relations (see section 2.1.4), that is, for identifying an object as *here* or *there*. In the case of projective relations, spatial indexing is required to identify the reference and located objects in the spatial representation. *Reference frame adjustment* involves establishing a correspondence between a projective predicate in the conceptual representation and a region of space in the spatial representation. As discussed in the previous section, such correspondence is guided by the axial structure of the reference frame which is imposed on or extracted from the object indexed as reference. This process involves the following steps. First, the origin of the reference frame is aligned with the centre of the reference object. Secondly, the axes are rotated to the relevant orientation, depending on the type of reference frame adopted. Thirdly, the directions of the axes are established, that is, the base axes are defined. Finally, the distance of the reference frame is set (Carlson & Van Deman, 2004).[8] Once the axial structure of the reference frame has been adjusted so that its base axes have been defined, a projective predicate can be assigned to the region adjacent to the relevant axis.

The theory assumes spatial indexing and reference frame adjustment to be voluntary processes that can be flexibly executed depending on the task at hand. For example, when locating an object as *next to* another there is no need to establish the direction of the relevant axis. All that is required is to identify that axis as the sagittal. As such, frames of reference and spatial indexes are regarded as mechanisms of attention in that they orient attention to objects and regions of space in accordance with the task demands (Logan, 1995).

A vast number of studies provide empirical support for the processes involved in establishing these correspondences. For instance, there is support for the idea that basic relations only involve spatial indexing whereas projective relations also require reference frame computations, and that spatial indexing and reference frame computations are distinct processes (Carlson-Radvansky & Jiang, 1998; Logan, 1995). The position of a distracter in a scene does not seem to influence the apprehension of a spatial relation, which indicates that the distracter is merely indexed and its relation to the reference object is ignored, which in turn suggests that spatial indexing precedes reference frame computation (Carlson & Logan, 2001). Origin, orientation and direction appear to be distinct parameters of reference frames, for both intrinsic and relative frames, that can be voluntary adjusted depending on task demands (Carlson-Radvansky & Jiang, 1998; Landau, 2003; Logan, 1995). When assigning prepositions referring to a vertical axis (i.e., *above, below, over* and *under*) the relative frame of reference seems to be dominant when aligned with an absolute reference frame (Carlson-Radvansky & Irwin, 1993; Friederici & Levelt, 1990). However, when no absolute reference frame facilitates the relative frame, the intrinsic reference frame appears to be dominant (Carlson-Radvansky & Logan, 1997). The intrinsic reference frame is accepted to a greater extent when assigning (Swedish) projectives referring to the horizontal axes (i.e., *framför, bakom* and *bredvid*), and the application of the intrinsic reference frame is facilitated when aligned with an absolute frame (Hörberg, 2004). The choice of reference frame can also be affected by the social context when assigning projectives referring to the saggital axis (i.e., *in front of* and *behind*); (Grabowski & Miller, 2000; Grabowski & Weiss, 1996). When reference frames are in conflict, multiple frames appear to be active simultaneously (Carlson-

[8] Logan (1995) and Logan & Sadler (1996) refer to this parameter as *the scale* of the reference frame. However, following Carlson and Van Deman (2004), *distance* is used to refer to this parameter in the present work.

Radvansky & Irwin, 1994), an activation process that seems to be automatic (Carlson-Radvansky & Logan, 1997), and the selection process among the active frames involves inhibition of the corresponding axis of a non-selected reference frame (Carlson-Radvansky & Jiang, 1998). Also, distance appears to be a distinct parameter of reference frames, independent of axis, as the maintenance of a specific distance in a prime relation seems to facilitate the apprehension of a probe relation, even when the prime and probe axes differ (Carlson & Van Deman, 2004). Finally, changes in the neural activity of the brain appear to correspond to the process of spatial indexing, reference frame computation and the process of establishing the goodness-of-fit between spatial concept and a specific spatial relation (Carlson, West, Herndon & Taylor, 2002).

2.3.4. Spatial template alignment

Once a correspondence between the conceptual and spatial representations has been established, the validity of that correspondence has to be evaluated. That is, the relation between two objects in a scene might be a better or worse example of a projective concept. To establish such validity, a region of acceptability, or a *spatial template*, is imposed on the reference object in the spatial representation and aligned with the axial structure of the reference frame. This is illustrated in figure 3. The validity of the correspondence between *above* and the spatial relation between the plane in figure 3 and an object depend on the placement of that object. The spatial relation between the plane and an object in region *a* is a good example of *above*, the relation between the plane and an object in the *b* regions is an acceptable example of *above*, whereas the relation is a bad example of *above* if the object is located in any of the *c* or *d* regions.

Logan & Sadler (1996) show empirical support for this idea. In one experiment, they demonstrate how space around a reference object is parsed in to regions of acceptability, depending on the spatial concept at hand. Subjects were shown displays consisting of a reference object placed in the middle of an invisible 7×7 grid. Across trials, a located object was placed in each of the empty cells of the grid. The task for each placement was to rate how acceptable a given spatial preposition was in describing the spatial relation between the reference and located object. The averaged ratings define regions of acceptability for each spatial relation. The cells that receive high ratings make up a spatial region which constitutes a good example of the spatial relation at hand. Cells that receive medium ratings define a region that is an average example of the relation. Cells with low ratings establish a region which is a bad example of that relation. In this way, each spatial relation correspond to a region of acceptability that is made up of regions of good, average and bad examples of the relation at hand.

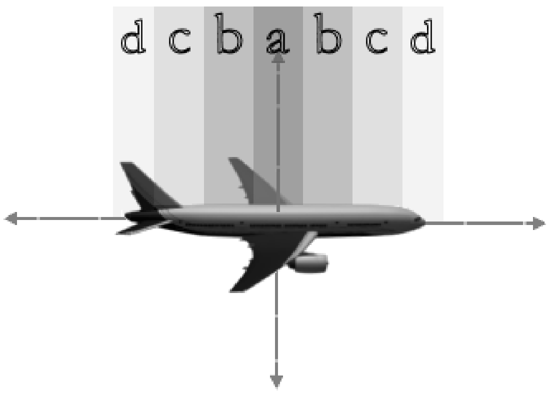


Figure 3. A spatial template establishes regions of acceptability that are used to determine how well a specific spatial relation instantiates a projective concept. The relation between an object in region *a* and the plane is considered a good example of *above*. If the object is positioned in the *b* regions, the relation is an acceptable example, whereas the relations between objects placed in regions *c* or *d* are bad examples of *above*.

Specifically, *above*, *below*, *over* and *under* were associated with regions of acceptability for which acceptance was at its highest along the vertical axis of the reference object and intermediate alongside the axis, as in figure 3. For the regions relevant for *left of* and *right of*, on the other hand, acceptance was greatest along the horizontal axis. This indicates that the template is defined with respect to the axial structure of the reference frame.

Logan & Sadler (1996) also had subjects rate the similarities of various prepositions. The similarity ratings were subjected to multidimensional scaling analysis, a statistical technique for exploring similarities and differences in a data set, and compared with similarity estimates of the data from the previous experiment that had been analyzed with the same technique. The correlations between these results were high, showing that similarity judgments about the meaning of spatial prepositions correspond to similarities between regions of acceptability associated with the respective prepositions. This suggests that the meanings of spatial prepositions are defined with respect to a spatial template.

Hayward & Tarr (1995) provide further support for this idea in similar experiments concerned with regions of acceptability. This study also included non-linguistic memory tasks, in which subjects had to recall the position of a located object with respect to a reference object, independent of any linguistic encodings of the relations at hand. The results of the linguistic task yielded similar regions of acceptability as those obtained by Logan & Sadler (1996), and the results of the memory tasks corresponded to these regions. That is, recall was at its best when the located object was positioned within a region of high acceptability, along any of the axes of the reference object.

Also, when multiple reference frames are active (see the previous section), spatial templates corresponding to each reference frame seem to guide the computation of complex spatial templates, whose forms are based on the weightings associated with each separate template. This weighting is further affected by personal preferences of reference frame selection (Carlson-Radvansky & Logan, 1997).

These results provide support for the idea that the meanings of projective prepositions are based on regions of acceptability aligned with the axial structure of the reference frame, which, in turn, indicates that projective prepositions schematize the reference object to an axial structure and the located object to a point. Also, the fact that the regions of the linguistic task corresponded to the regions of the non-linguistic tasks in the Hawyard & Tarr (1995) study indicates that there exist a direct mapping between non-linguistic spatial representations and spatial prepositions.

However, these results were not confirmed in a similar cross-linguistic study conducted by Munnich et al. (2001) in which the reference object extended in the vertical. The located object was vertically aligned with the reference object at more than one position, and recall was facilitated at these positions, independent of the axes of the reference frame. Thus, the shape of the reference object did have an influence in this non-linguistic task, a point further discussed in the next section.

2.3.5. Computation of goodness-of-fit: The Attention-Vector-Sum Model

Once a spatial template has been imposed on the reference object and aligned with respect to the axes of the reference frame, the goodness-of-fit between the spatial relation at hand and the spatial concept has to be established. This is, according to Logan & Sadler (1996), done by comparing the position of the located object to the template.

However, Carlson, Regier & Covey (2003) note both theoretical and methodological problems with this idea. First, a spatial template aligned with respect to the axes of the reference frame, as illustrated in figure 3, is merely an explication of a region of acceptability and does not by itself explain how the perceptual system defines such region. There is still the need for a theory of the computational process of establishing a goodness-of-fit between a relation and a spatial concept. Secondly, the studies reported in the previous section, except for the Munnich et al. (2001) study, either implicitly or explicitly presuppose that the spatially related objects schematize to points. Since the probed positions in the experiments were made up by cells in which the objects were centred, there was only one position in the vertical or the horizontal plane at which the objects were aligned and it was the centre points of the objects that were aligned at these positions. Thus the objects were either perfectly aligned or misaligned, which in effect reduces the spatially related objects to points. In such cases, inferring the origin of the reference frame is a trivial matter; it will always coincide with the centre of the cell in which the reference object is located. However, when considering spatially extended objects, the origin of reference frame can only be established with respect to the prototypical regions of a template and in such cases the explanation provided by Logan & Sadler (1996) suffers from circularity. The position of the template is inferred with respect to the reference frame whereas the position of the reference frame can only be established with respect to the regions of the template. Thus the conception of spatial templates as regions of acceptability defined with respect to the axes of the reference frame presupposes that the spatially related objects schematize to points and that their shapes are irrelevant. However, as suggested by the study conducted by Munnich et al. (2001), the shape of the reference object does seem to be of importance in establishing regions of acceptability and therefore influences the shape of the templates.

The *Attention-Vector-Sum Model*, a development of a constrained connectionist model of the apprehension of spatial relations by Regier (1996), assumes that the apprehension of projective relations depend on the degree of alignment between a number of relational orientations and a reference orientation, determined by the relevant axis of the reference frame (Carlson et al., 2003; Regier & Carlson, 2001; Regier, Carlson & Corrigan, 2005).

The model, henceforth referred to as the AVS-model, accounts for the computational process of establishing a goodness-of-fit between a spatial relation and a spatial concept and aims at grounding this process in genuine perceptual processes. The model is based on the observation that the apprehension process of projective relations involves attention to objects and regions in space (Logan, 1995); (see section 2.3.3.). The model is also motivated by neurological evidence for the existence of orientation-sensitive cells in both visual and motor cortices of the human and monkey brain that respond to specific orientations of visual stimuli or the orientations of the arms. Specifically, overall orientation or direction is represented by the weighted output of several orientation sensitive cells. The visual cortex of the human brain appears to represent the perception of motion direction in this way and the orientations of the arms of the monkey can be predicted by the joint output of orientation-sensitive cells in its motor cortex (Carlson et al., 2003).

According to the model, the *centre-of-mass orientation* is the orientation of an axis connecting the centre-of-mass of the reference object with the centre-of-mass of the located object, and the *proximal orientation* is the orientation of an axis connecting the reference object with the located object where the two objects are closest. Crucially, acceptability judgments about a projective depend on the alignment between these orientations and some reference orientation, such as upright vertical in the case of *above* or *below*. When the orientations are aligned with upright vertical, the objects are vertically aligned with each other, and the relation between them is a perfect example of *above* or *below*. However, an increase in the deviation between the centre-of-mass orientation and upright vertical will reduce the acceptability of the relation and a deviation between the proximal orientation and upright vertical will enhance this reduction.

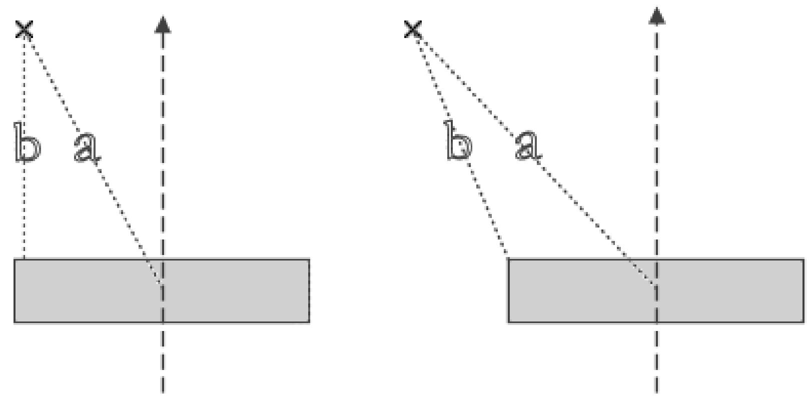


Figure 4. How appropriate *above* is to describe the spatial relation between the rectangle and the "x" depend on the deviation of the centre-of-mass (axes labelled a) and proximal orientation (axes labelled b) from upright vertical. The left panel is a better example of *above* than the right because the deviation of centre-of-mass orientation from upright vertical (the dashed vertical lines) is lower in the left panel and the proximal orientation is aligned with upright vertical in the left panel but not in the right.

This is illustrated in figure 4, in which the rectangles represent a reference object, the "x"s represent the centre-of-mass of a located object and the dashed vertical lines mark upright vertical. In the panel to the left, centre-of-mass orientation, the orientation of the axis labelled *a*, deviates from upright vertical whereas proximal orientation, the orientation of the axis labelled *b*, is aligned with upright vertical. In the panel to the right, on the other hand, both centre-of-mass orientation (orientation of axis *a*) and proximal orientation (orientation of axis *b*) deviate from upright vertical. Furthermore, the deviation between the centre-of-mass orientation and upright vertical is higher in the right panel than in the left. For these reasons, the spatial relation between the "x" and the rectangle in the left panel is a better example of *above* than the relation in the right.[9]

Centre-of-mass orientation and proximal orientation can account for the results of the Munnich et al. (2001) study (see the previous section). That is, the fact that memory was facilitated when the located object was positioned off-axis but vertically aligned with the reference object could be due to the fact the proximal orientation between the objects was aligned with upright vertical. Thus the AVS-model can account for the spatial extension of the reference object and does not presuppose that it schematizes to a point.

The model assumes the following computational steps, illustrated in figure 5. An attentional beam is focused at the point of the reference object closest to the located object making those parts of the reference object closest to the located object maximally attended. In the figure, the beam is illustrated by the dashed circle. A number of orientations, or *vectors*, are rooted at various positions across the reference object and projected towards the located object. These vectors are illustrated as the dotted lines in the figure. Importantly, the distribution of attention determines the weight of the vectors, which is illustrated by the brightness of the dotted lines in the figure.

The weight is high for vectors rooted closely to the centre of the beam, illustrated by the dark lines, whereas the weight of the vectors rooted in the periphery of the beam is low, illustrated by the lighter lines. The sum of the weighted vectors yield an orientation, axis *a* in the figure, which is compared with a reference orientation, which is the orientation of the relevant axis of the reference frame. In the case of *above*, this reference orientation is upright vertical, labelled *b* in the figure. Thus how good an example the relation between the rectangle and the "x" is of *above* depends on the alignment between the orientation of the vector sum and upright vertical.

9 In the present example, these factors are confounded. However, depending on the shape of the reference object and the position of the located object, this is not always the case. See Regier (1996) and Regier and Carlson (2001) for examples.

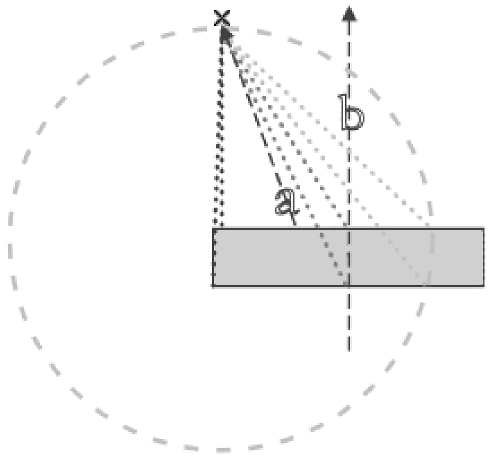


Figure 5. Example of the AVS-model. An attentional beam (dashed circle) is focused on the reference object, yielding a number of weighted vectors (dotted lines) projected towards the located object whose sum (axis *a*) is compared with a reference orientation (axis *b*).

Finally, the size of the beam depends on the distance between the reference and located object, as the boundary of the beam coincides with the point of the located object that is closest to the reference object. Therefore, the radius of the beam is always equal to the distance between the objects, as seen in the figure.

The model makes the following predictions. First, acceptability judgments about projective prepositions depend on the shape of the reference object, as the positions at which the vectors are rooted depend on the shape of the object. Second, judgments are influenced by centre-of-mass and proximal orientations; acceptance is reduced as the deviation between the centre-of-mass orientation and the reference orientation increases and an increase in the deviation between the proximal orientation and upright vertical enhances this reduction. Thirdly, and contrary to earlier results (Carlson-Radvansky & Logan, 1997; Hayward & Tarr, 1995; Logan & Sadler, 1996), judgments are influenced by the distance between the spatially related objects, as the distance influences the size of the attentional beam which in turn affects the vector summation.

When the distance between the objects is small, the beam is narrow and vectors are rooted only in the part of the reference object closest to the located object. Therefore, the vector summation yields an orientation almost identical to the proximal orientation. In effect, the model predicts that centre-of-mass orientation will be of less importance when the objects are close. When the distance between the objects is large, on the other hand, the width of the beam will result in heavily weighted vectors rooted at positions all over the reference object, and the vector summation yields an orientation that matches the centre-of-mass orientation. Consequently, proximal orientation is of less importance when the objects are far apart. At medium distances, on the other hand, the vector summation yields an orientation which is intermediate between the centre-of-mass and proximal orientations, as in figure 5, and both orientations are of importance (Regier & Carlson, 2001).

In a series of sentence-verification experiments, Regier & Carlson (2001) provide good empirical support for these predictions. Specifically, they show that the AVS-model outperforms three other potential models of the apprehension of projective relations by generating predictions that best match the empirical data of the experiments.

These results show that spatial templates should be regarded as vector representations, as generated by the AVS-model, rather than prototypical regions emerging from the axial structure of the reference frame (Carlson et al., 2003). The AVS-model is a perceptually grounded theory of the computational process of establishing a template, rather than a mere description of such a region relative to the axial structure of the reference frame, that accounts for genuine geometric influences that cannot be accounted for with an axial representation. Vector representations do not presuppose that the reference object schematizes to a point and does not depend on the origin of the reference frame. The axes of the reference frame are used as the reference orientations with which the vector sums are compared but the origin of the frame is irrelevant in this process (Carlson et al., 2003).

2.4. FUNCTIONAL INFLUENCES ON LOCATIVE PREPOSITIONS

As discussed in section 2.2., traditional accounts of the meanings of locative prepositions assume that locative prepositions express a geometric relation of either a topological or dimensional nature between a reference object and a located object. Furthermore, according to this view, locative prepositions largely ignore the shape and the function of the spatially related objects by representing them schematically.

According to these accounts, the meaning of topological prepositions, such as *in* or *on*, is based on geometric concepts of a topological nature such as enclosure, in the case of *in*, or contiguity, in the case of *on* (Garrod et al., 1999). For example, according to the definition of *in* provided by Miller & Johnson-Laird (1976); (see section 2.2.1.), a located object can be said to be *in* a reference object if some part or the whole of the located object is perceived as being enclosed by the reference object. Also, such accounts put no constraints on the shape of the located object whereas the shape of the reference object is of some importance. For instance, *in* demands that the reference object has an interior whereas *on* requires a planar reference object (see section 2.2.2.). In the case of projectives, the reference object schematizes to the axial structure of the reference frame and the located object to a point, and the projectives express a geometric relation of a dimensional nature by referring to one of the base axes of the axial structure. The theories concerned with the apprehension of projective relations presented in the section 2.3. are consistent with the view that projective relations are defined solely with respect to the geometric relation between the spatially related objects. Furthermore, as argued in section 2.3.5., the conception of the spatial template as a prototypical region emerging from the axial structure of the reference frame presupposes that both the reference and located object schematize to points. The AVS-model, which treats the template as a vector representation, does take the shape of the reference object into account but treats the located object as a point.

However, it turns out that the geometric accounts are too simplistic and fail to capture the meaning of locative prepositions adequately. In some cases, the geometric definitions overgenerate to situations that would be inappropriate to describe with the preposition at hand. In others, they undergenerate and do not apply to situations that are perfectly describable with the preposition (Coventry & Garrod, 2004). This is illustrated in figure 6. The geometric definition of *in* provided by Miller & Johnson-Laird (1976); (see section 2.1.1.) is unable to account for the relation between the pear and the bowl in *a*, although *in* is acceptable in such a situation. However, the definition applies to the relation in *c*, although the pear cannot be said to be *in* the bowl in *c*. The definition thus both undergenerates and cannot account for situations like *a* as well as overgenerates to situations like *c*. Finally, geometric definitions of *on* which rests on the topological concept of contiguity fail to account for the relation between the pear and the branch in *d*, since the pear is, at large, not geometrically contiguous with the branch, although *on* is perfectly applicable to such a relation.[10]

[10] The definition of *on* suggested by Miller & Johnson-Laird (1976) does include the functional notion of support. However, as noted by Garrod & Ferrier et al. (1999), this notion is considered as a special constraint added to the essentially geometric definition and the definition is unable to account for situations like *d* in figure 5.

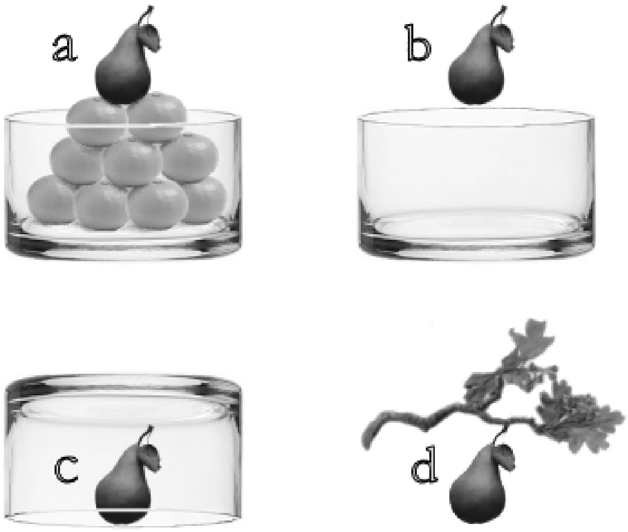


Figure 6. Geometric definitions of topological prepositions either undergenerate, i.e., are unable to account for situations perfectly describable by the prepositions at hand, or overgenerate by applying to situations which is inappropriate to describe with the preposition. Geometric definitions of *in* that rest on the topological concept of inclusion fail to account for the relation between pear and bowl in *a*, although *in* is acceptable in *a*, but apply to the relation in *c*, which is not an example of *in*. Geometric definitions of *on*, based on the topological concept of contiguity, cannot account for the relation between the pear and branch in *d* although the pear can be said to be *on* the branch in such a situation.

Furthermore, the view that the functions and fine-grained distinctions of the shapes of the spatially related objects are abstracted away also turns out to be wrong (Carlson-Radvansky et al., 1999; Coventry & Garrod, 2004, 2005; Coventry & Prat-Sala, 2001; Coventry, Prat-Sala & Richards, 2001). A number of extra-geometric factors of a functional nature seem to be of importance in the comprehension process of locative prepositions. These functional factors concern how the spatially related objects interact with each other and what functions the objects serve. (Coventry, 1998, 2003; Coventry & Garrod, 2004, 2005). Some of the empirical evidence for such influences is outlined in the present section.

2.4.1. Influences of force dynamics

As geometric definitions fail to adequately cover the range of situations in which the topological prepositions *in* and *on* apply, as illustrated in figure 6, it has been suggested that functional relations underlie the meaning of these prepositions (Coventry, 1998; Coventry & Garrod, 2004; Garrod et al., 1999; Garrod & Sanford, 1989; Vandeloise, 1994, 2005). Specifically, the meanings of the prepositions depend on constraints of the physical forces that the related objects exert on each other. The reference object needs to physically control the location of the located object by some degree of containment in the case of *in*, and by some kind of support in the case of *on*. *In* is thus a relation of *functional containment* and *on* a relation of *functional support* (Garrod et al., 1999) and the functional concept of *location control* (Coventry, Carmichael & Garrod, 1994; Coventry & Garrod, 2004; Garrod et al., 1999; Garrod & Sanford, 1989) shared by the prepositions explains why *in* is appropriate in situation *a* in figure 6, but not in *c* and why *on* is appropriate in *d*. The pear in *a* can be said to be *in* the bowl because the bowl physically controls the location of the pear in virtue of having a containment function. Although the pear is enclosed by the bowl in *c*, *in* is inappropriate since the bowl does not control the location of the pear in this situation. Importantly, *in* does not apply to the relation between the pear and bowl in situation *b*, although the geometric relation between the objects is identical to that in *a*. Thus the meaning of *in* cannot be strictly geometric. Finally, the pear in *d* is *on* the branch, although the pear and the branch are not geometrically contiguous, because the branch controls the location of the pear.

A number of studies provide empirical support for the influence of location control on the meaning of *in* and *on*. For instance, Garrod et al. (1999) show that confidence in *in* and *on* provided in sentence verification tasks correlates with confidence in non-linguistic judgments of location control. Coventry & Prat-Sala (2001) show that confidence in *on* in sentence verification tasks with static scenes depends on the perceived degree of support the reference object provides for the located object. Also, the use of *in* in a sentence completion task depended on the evidence for location control in various videotaped scenes involving movement, such as whether the movement of the located object corresponded to the movement of the reference object (Coventry, 1998). The same results were obtained in a similar experiment conducted with 4 to 7 year old children (Richards, Coventry & Clibbens, 2004).

Thus the meanings of spatial prepositions seem to depend also on the force dynamics involved in the relation between the objects, that is, how the objects interact with respect to physical force. Following Talmy (1988), force dynamic patterns as conceived within linguistic and conceptual representations of the world, involve a steady-state opposition between a focal force entity, an *agonist*, and some opposing force, an *antagonist*. Force-dynamic patterns depend on the different types of interactions between the two; whether the agonist is able to manifest its force tendency or is overcome by the opposing force of the antagonist (Coventry & Garrod, 2004; Talmy, 1988). Thus both a dynamic as well as a static scene might involve force. In the former case the force of the agonist overcomes the force of the antagonist, but not in the latter (Vandeloise, 2005). For example, the pear in scene *d* in figure 6 is perceived as a force entity with a tendency to move in the direction of the force of gravity. However, this tendency is overcome by the opposing force provided by the support of the branch.

A number of studies show that force dynamics are of importance also for the comprehension of projectives. Regier (1996) provides theoretical support for this idea by arguing that the comprehension of vertical projectives is dependent on *the direction of potential motion*.[11] Support for either *above* or *over* is provided when the located object is positioned so that the influence of the force of gravity would cause it to hit the reference object, and the meanings of vertical projectives thus imply that one of the related objects would hit the other under the influence of gravity. Coventry & Mather (2002) provide empirical support for this idea by showing how appropriate judgments about *over* correspond to non-linguistic knowledge about how objects fall to the ground. Subjects were shown pictures of a building that stood in the flight-path of a plane and informed that the plane was on a mission to bomb the building. Subjects either had to select one of a number of locations horizontally aligned above the building, at which they thought the plane could be described as being *over* the building, or they had to rate how appropriate *over* was in describing the relation between the plane and the building with the plane positioned in each of these locations. They also had to select the location in which they thought the plane had to drop the bomb in order to successfully hit the building, or rate the locations for their appropriateness to indicate where a bomb should be dropped in order to hit the building. The results of the linguistic tasks corresponded to the non-linguistic tasks in which subjects had to report or rate at which locations they thought the bomb had to be dropped in order to hit the target. Thus linguistic judgments of *over* correspond to non-linguistic judgments about how objects fall (Coventry & Garrod, 2004; Coventry & Mather, 2002). Specifically, *over* is considered more appropriate when

[11] Note, that the direction of potential motion will correspond to upright vertical in most cases. However, as in scenes involving a third object, this is not always the case. See Regier (1996) for an example.

the located object is considered to be in a position at which the direction of potential motion will cause an impact with the reference object.

Coventry et al. (2001) provide further support for the importance of force dynamics in the comprehension of vertical projectives in a series of sentence-verification tasks. They manipulated geometric and functional constraints in two sets of images, in order to explore the relative influence of these factors. In the first set, one of the objects had a *protecting function*, protecting the other object from falling objects. In the second it had a *threatening function*, by potentially pouring, spilling or dropping its contents on or in the other object if tilted. The geometric manipulation in the images consisted of placing either the protecting object in the first set or the target object of the second set in vertical alignment with the other object, at an angle of 45 degrees or at an angle of 90 degrees to the other object. The functional manipulation consisted in varying the functional interaction portrayed in the images; the protecting or threatening function displayed in the images was either fulfilled or unfulfilled, or the context needed to make that distinction apparent was absent. For example, one set of images portrayed a man holding an umbrella with a protecting function. The umbrella was either held directly above the man, at a 45 degree angle in front of and above the man or at a 90 degree angle in front of the man. Also, the umbrella was either fulfilling its function by protecting the man from rain or it failed to do so, or the rain was absent in picture and it could not be established whether the protecting function was fulfilled. Subjects' task was to rate how appropriate the vertical projectives *over*, *under*, *above* or *below* were in describing the relations between the objects in the images. Unsurprisingly, ratings depended on the geometric manipulations and decreased as the vertical alignment between the objects decreased. Importantly, the functional manipulations had a significant impact on ratings. Ratings of images in which the function was fulfilled were highest, followed by ratings of images in which it could not be established whether function was fulfilled, whereas ratings of the images in which function was unfulfilled were the lowest. Thus acceptability judgments about vertical projectives do not only depend on geometric factors but also upon judgments of whether or not one of the objects fulfils a protecting or a threatening function. As such judgments depend on the inferred force-dynamic interaction between the objects, the experiments give further support for the idea that the meaning of vertical projectives depends on the force-dynamic pattern involved in the relation. In parallel to the functional concept of location control of importance for the meaning of topological prepositions, Coventry & Garrod (2004) suggest that the meanings of vertical projectives depend on the functional concepts of *threatening contact* and *blocking contact* as the meanings of vertical projectives to some extent depend on whether or not a threatening or protecting/blocking function is fulfilled.

Carlson-Radvansky et al. (1999) conducted an experiment similar to the sentence-verification tasks conducted by Logan & Sadler (1996) and Hayward & Tarr (1995) of particular importance for the present work. Subjects had to rate the appropriateness of the preposition *above* in describing the relation between a piggy bank and a coin when positioned in different positions in an invisible grid around the piggy bank. The functional manipulation, conducted between subjects, consisted in varying the position of the slot on top of the piggy bank. If *above* only depends on the geometric relation between reference and located object, ratings should be at their highest when the coin is positioned directly above the piggy bank, vertically aligned with the centre-of-mass of it, in accordance with the Logan & Sadler (1996) and Hayward & Tarr (1995) studies. However, the peak of the ratings varied as a function of slot position, and ratings were at their highest when the coin was directly above the slot and not directly above the centre-of-mass of the piggy bank. Thus subjects took into account at which position the coin had to be dropped in order to be successfully inserted into the piggy bank. These results are consistent with the results of the Coventry et al. (2001) study; judgments of *above* depended on whether the coin fulfilled its threatening function by being in position at which it would hit the slot of the piggy bank. Importantly, the study shows how functional factors involving force-dynamics can influence the shape of the spatial template and that the purely geometric factors suggested by Regier & Carlson (2001); (see section 2.3.5) are not the only factors of importance.

2.4.2. Influences of object knowledge and context

Implicit in the discussion about the influence of force dynamics on the meanings of spatial prepositions is the fact that knowledge about the functions of the spatially related objects and knowledge about how they typically interact also influence their meanings. Influences of force-dynamic interactions often presuppose such knowledge. For instance, in order to make judgments about whether or not a threatening or protecting function is fulfilled, one has to know what functions the spatially related objects serve, i.e., if one of the objects has a threatening or protecting function, or if the other object functions as a potential target. Coventry et al. (1994) have shown that *over* is considered more appropriate for describing the relation between a jug and a glass when the jug is filled with water, making the threatening function of the located object more salient, and Coventry & Prat-Sala (2001) show that functional manipulations of the reference object can also influence the appropriateness of *over*. Furthermore, the results of the Carlson-Radvansky et al. (1999); (see section 2.4.1.) presuppose that subjects know that piggy banks function as containers and which part of the object is of importance to fulfil that function (i.e., the slot).

Carlson-Radvansky et al. (1999) provide further support for the importance of knowledge about the functions of objects in a second experiment, also of significance for the present work. They had subjects place pictures of located objects either *above* or *below* pictures of reference objects. The located objects could interact with some functional part of their respective reference object, from above or from below, and the functional parts of the reference objects were distant from the centre-of-mass of the objects. For example, one object pair consisted of a toothbrush as reference object and a toothpaste tube as located object. The toothpaste tube could interact with a functional part of the toothbrush, its bristles, and this part was distant from the centre-of-mass of the toothbrush. Depending on the orientation of the reference object, the functional part was either aligned with its centre-of-mass or distant from it. For example, in one picture the toothbrush was oriented so its bristles were facing the viewer and in the other the bristles were to the left in the picture. Also, the located object was either functionally related or unrelated to the reference object, but both objects afforded the same type of interaction with the reference object. For example, in the unrelated condition the toothpaste tube was replaced with a tube of oil paint. If the comprehension of *above* or *below* only depends on the geometric relation between the objects, the placements of the located object should be directly above the centre-of-mass of the reference object independent of the location of the functional part of the reference object in accordance with Logan & Sadler (1996) and Hayward & Tarr (1995); (see section 2.3.4.). However, when the functional part of the reference object was dissociated from the centre-of-mass of the object, the placements of the located objects were significantly biased in the direction of the functional part. For example, the placements of the toothpaste tube were biased towards a position at which the threatening function of the toothbrush tube is fulfilled. In such position, tip of the tube is vertically aligned with the bristles of the toothbrush, as illustrated in figure 7 below.

The placements thus depended on the subjects' knowledge about functional aspects of the related objects. Knowledge about the functions of the objects in the scenes biased the placements of the located objects towards positions at which the threatening function

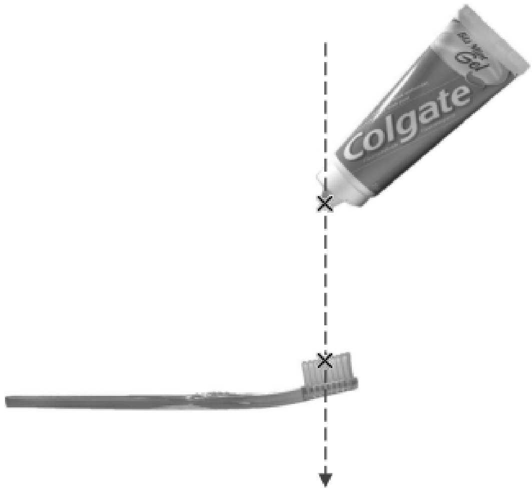


Figure 7. Judgments about force dynamic interactions between objects often presuppose knowledge about the functions of those objects. In order to place a toothpaste tube above a toothbrush in a manner that affords their interaction, the tip of the tube has to be vertically aligned with the bristles of the toothbrush, and the placement of the tube thus depends on knowledge about the functional parts of the objects.

of the located objects could be fulfilled, as illustrated in the figure. This shows that factors to do with force-dynamic patterns often depend on factors concerned with object knowledge. However, these placements were never fully biased to such positions. Rather, the located objects were positioned in between the functional part of the reference object and its centre-of-mass which indicates that both geometric and functional factors influenced the placements, an observation further discussed in section 2.5.1.

The placement bias was also stronger for functionally related objects than for functionally unrelated objects. Placements were thus also influenced by knowledge about whether or not the objects were functionally related. The fact that a bias was present for unrelated objects shows that placements also depended on judgments about the potential interactions between the objects in the specific context. These results were confirmed in a second experiment conducted by Coventry et al. (2001), identical to the experiment reported in section 2.4.1., in which functionally unrelated objects were included. For example, in the non-functional images corresponding to the images of a man holding the umbrella, the man was protecting himself with a suitcase. Thus, the protecting function in the non-functional images was either fulfilled or unfulfilled with objects that usually serve other functions. As in the first experiment, ratings in which the function was fulfilled were highest, regardless of whether or not the threatening or protecting object was appropriate for fulfilling that function. However, the influence of function was higher for the functionally related images than for the functionally unrelated images. Finally, the results of the Coventry & Mather (2002) study, reported in section 2.4.1., further show how judgments of projectives are influenced by context. Not all of the subjects in the experiment were informed that the plane was on a bombing mission. Those who received this information reliably more often picked a location for *over* which corresponded to the position at which the bomb had to be dropped in order to hit the building. When the building was referred to as a *target* the choice of that position was also reliably higher. Overall, these results show that knowledge about whether or not the objects are functionally related and about how they interact in the specific context also influences judgments about the appropriateness of projectives.

Functional knowledge and context also influence the applicability of topological prepositions. For instance, *in* is used more often and considered to be more appropriate in describing relations between solid objects and a reference object when the reference object functions as a container of solids (i.e., a bowl) than a container of liquids (a jug) (Coventry, 1998; Coventry et al., 1994). This effect is further enhanced by adding water to the container of liquids to make its liquid-containment function more salient and thereby rendering *in* even less appropriate (Coventry et al., 1994). The appropriateness of both *in* and *on* depends on how the reference object is labelled, independent of object shape. Labelling the reference object as an object with a typical containment function, i.e., as a *bowl,* renders *in* more appropriate whereas labelling it as an object with a typical support function, i.e., as a *plate*, makes *on* more appropriate (Coventry et al., 1994). When a reference object is supporting a located object and the degree of location control is weak, *on* is considered more appropriate if the objects are functionally *unrelated* as the small degree of location control is more salient for functionally unrelated objects (Coventry & Prat-Sala, 2001). Finally, a suitable context can make *in* more appropriate in situations where the located object is clearly not enclosed by the reference object (Coventry, 1999).

2.4.3. Functional influences on reference frame selection

Functional factors have also been shown to influence the process of reference frame selection (Carlson-Radvansky & Radvansky, 1996; Carlson-Radvansky & Tang, 2000; Hörberg, 2004), contrary to the view of Miller & Johnson-Laird (1976) that the reference frame selection process is a trivial matter (see section 2.2.2.). As discussed in section 2.1.5., when the intrinsic frame of reference is adopted, the axial system of the object itself is used and the orientation of the axes depends on the inherent features of that object (Fillmore, 1997; Hörberg, 2004; Miller & Johnson-Laird, 1976). The vertical axis is the axis that is aligned with the direction of the force of gravity when the object is positioned in its typical orientation. The horizontal axes and their base axes (see section 2.1.5.) are usually determined on functional grounds. For example, the base axis that is the *front* axis of most artefacts corresponds to the side which we face when we use them, such as the front of a stereo or a TV. The *front* axis of other human beings corresponds to the side we face when we interact with them. Thus the orientation of the inherent axes of objects are largely determined on functional grounds; the inherent *front* axes of objects often correspond to the side that permits access, interaction or intended usage. The inherent *up* axis often correspond to that side which is aligned with the force of gravity when the object is oriented in a fashion which permits access, interaction or usage.

The intrinsic frame of reference puts focus on the relations between objects, independent of a point-of-view (Miller & Johnson-Laird, 1976). As these relations are largely based on functional aspects of the objects, the intrinsic reference frame thus focuses attention on the functional relation between the objects (Carlson-Radvansky & Radvansky, 1996; Hörberg, 2004). Consequently, spatial descriptions based on the intrinsic reference frame should be more accepted when the related objects are functionally interacting. Carlson-Radvansky & Radvansky (1996) and Carlson-Radvansky & Tang (2000) provide empirical support for this idea by showing that the intrinsic reference frame is considered more acceptable and is selected more often when the spatially related objects afford interaction or when they are functionally related.

Of importance to the present work, Hörberg (2004) shows a preference for an intrinsic orientation of the reference frame when the objects are functionally related for Swedish- speaking subjects using Swedish projective terms. This preference is further enhanced by the presence of an absolute reference frame, aligned with the intrinsic reference frame. In a sentence-verification task subjects were shown pictures in which the intrinsic reference frame was misaligned with the relative reference frame and had to rate the appropriateness of descriptions involving both vertical and horizontal projectives in Swedish. These descriptions always relied on the intrinsic reference frame. The located object was either functionally related or unrelated to the reference object. Also, a visual context giving rise to an absolute reference frame, aligned with the intrinsic frame, was either present or absent. If multiple reference frames are active simultaneously (Carlson-Radvansky & Irwin, 1994), and the shape of the complex spatial template depend on the influence of each reference frame (Carlson-Radvansky & Logan, 1997), one would expect higher ratings with two frames of reference present (see sections 2.3.3. and 2.3.4.). Ratings of the descriptions were higher when the objects in the images were functionally related. The presence of an absolute reference frame aligned with the intrinsic frame also yielded higher ratings, and ratings were at their highest when the objects where functionally related and an absolute frame was present. As with the Carlson-Radvansky & Tang (2000) studies, these results show that the intrinsic reference frame is considered more acceptable when the objects in the scene are functionally related and the acceptance is further enhanced when an absolute reference frame is aligned with the intrinsic frame, as predicted by Carlson-Radvansky & Logan (1997); (see section 2.3.4.). These results show that Swedish projectives too are influenced by functional factors in a part of the comprehension process.

2.4.4. Differences between prepositions

Topological prepositions appear to be more sensitive to functional factors than projective prepositions and the functional concept of location control appear to be of more importance than the concepts of threatening and protecting contact. Indeed, some functional accounts of the meaning of *in* and *on* suggest that functional containment and functional support are central to their meanings and that the geometric constraints associated with them are secondary (Coventry, 1998; Garrod & Sanford, 1989; Vandeloise, 1994, 2005). Furthermore, acceptability judgments about different projective prepositions are differentially influenced by functional factors. Coventry et al. (2001) and Coventry (1999) suggest that spatial prepositions may constitute a continuum from those whose meaning is mainly functional to those which has a primarily geometric meaning and that this difference is related to the extent to which the prepositions are regarded as polysemous.

According to this view, acceptability judgments about the vertical projectives *over* and *under* are more sensitive to functional influences than *above* and *below*. Many of the experiments outlined in sections 2.4.1 to 2.4.3. provide support for this. Coventry & Mather (2002) failed to find a correspondence between acceptability judgments about *above* and non-linguistic judgments about how objects fall, which indicates that the meaning of *above* not depend on the functional concept of threatening contact. Also, functional influences were much stronger on acceptability judgments about *over* and *under* than on judgments about *above* and *below* in the experiments conducted by Coventry et al. (2001); (see sections 2.4.1. and 2.4.2.) and the manipulations of the reference object that influenced judgments about *over* in the study conducted by Coventry & Prat-Sala (2001); (see section 2.4.2.) did not affect judgments about *above*. Finally, the study conducted by Hörberg (2004), presented in section 2.4.3., showed that the influence of function on the acceptance of the intrinsic reference frame is stronger for horizontal than vertical projectives.

2.4.5. The connection between form and function

As discussed in section 2.4.2., judgments about force dynamic interactions between spatially related objects often presuppose knowledge about the functions of those objects and knowledge about how they usually interact. Furthermore, functional knowledge about objects often implies knowledge about the shape of those objects and functional interactions between objects often depend upon such knowledge. In the second experiment of the Carlson-Radvansky et al. (1999) study, reported in section 2.4.2., object knowledge biased the placements of the located objects towards *the parts* of the reference objects at which the threatening function of the located objects could be fulfilled. In case of the toothpaste tube and the toothbrush, illustrated in figure 7, the threatening function is fulfilled when the toothpaste tube is positioned in a location at which a part of the tube, its tip, is vertically aligned with a part of the toothbrush, its bristles, so that the toothpaste can be placed on the bristles of the toothbrush.

According to Tversky (2005), form and function are highly correlated and at times causally related as form can determine function. For example, bowl-shaped objects in general are good for storing things in and thus function as containers; they afford containment. Objects are associated with interactive qualities, or *affordances*, which relate perceptual features of their shape and orientation to possible interactions with them and thus determine what functions they potentially serve (Glenberg & Kaschak, 2005; Tversky, 2005). Specifically, *parts* of objects are important in determining what functions those objects serve, as parts support inferences about functions based on appearance. As knowledge and reasoning about functional features of objects is important in categorization, parts provide the information needed to categorize objects (Tversky, 2005). A number of studies provide support for this by showing that object categorization largely depends on the parts of the objects and the functions those parts serve (Carlson, 2000; Tversky, 2005). Furthermore, the parts of objects that are crucial for their function are detected faster and more accurately in speeded object recognition tasks, suggesting that people pay more attention to functional than non-functional parts (Carlson, 2000; Regier et al., 2005). Thus, the functional influences on acceptability judgments about locative prepositions reported above largely depend on the affordances of the spatially related objects, which in turn depend on the shape and the parts of those objects.

Carlson & Covell (2005) provide some additional support for this idea. Based on the results of the second experiment in the Carlson-Radvansky et al. (1999); (see section 2.4.2.), they set out to investigate which functional features of the reference object had influenced the functional bias reported in the experiment. This was done by further analyzing the results. Analyzes were conducted on the differences in the magnitude of the functional bias for individual pairs of objects. In the first analysis, the authors classified the objects pairs along a number of dichotomized dimensions, based on features of the reference objects that intuitively seemed to influence the bias. The reference objects of each pair were classified as either having or lacking the feature. The critical question was if the functional bias significantly differed for the class of object pairs with a reference object that had a specific feature compared with the class of object pairs with a reference object that lacked that feature. In the second analysis, no assumptions about which features had been of importance were made. Instead principal components analysis was used, a method in which the factors that account for most of the variance within a data set are identified. Relevant features were then inferred for those factors that accounted for more than 10 percent of the variance, based on which items of object pairs within the data that were correlated with each factor. That is, based on the differences in the magnitude of the functional bias for items of object pairs, clusters of individual items were identified and the relevant feature for each cluster was inferred based on which items it contained.

The relevant features of the first analysis, only concerned with features of the reference object, were whether or not the offset between the functional part and the centre-of-mass of the object was large, whether the object made any changes to the functionally related object, such as a ketchup pump, a lighter or a can opener, and finally, whether the relevant functional part of the object was considered to be most vital for the object's function. The second analysis identified groups of items that appeared to share the following features. The first group included reference objects with the ability to dispense objects or substances, such as a ketchup pump or a newspaper dispenser. The second group contained objects which afforded interaction with the other object through an opening, such as a piggy bank or a hand dryer. The third group consisted of objects whose interaction required high precision of use, such as a pencil sharpener or a watering can. The fourth group contained objects whose functional part was a flat surface that afforded support, such as a toothbrush or a CD player and, in contrast, objects whose functional part was an opening into which another object is inserted, such as a blender or a video recorder. The fifth and final group consisted of objects which could interact with a limited number of other objects, such as a can opener and a dish washer. These features thus appeared to be related to how the functional part of the objects in each group interacted with the other object.

Carlson & Covell (2005) conclude that it is not only the functional features of the reference object that are important to the functional relation between two spatially related objects. Depending on its shape, a reference object may afford several functions and the located object will make one of these functions salient by establishing a context in which the reference object is used (Carlson & Covell, 2005). That is, which functional part of the reference object that is considered to be the most salient largely depends on the function of the located object. The features identified in the Carlson & Covell (2005) study appear to depend on the following key aspects of an object. First, *the position of the functional part of the object* appears to be of importance, as the functional bias depended on the offset between the functional part and the centre-of-mass of the object. Secondly, *the precision required to interact with the functional part* is of influence, which often depends on *the size of the functional part*. Thirdly, *the shape of the functional part* is of importance, as the bias depended on whether the functional part had a flat surface or consisted of an opening. Fourthly, *the type of function the object affords* appears to be important, as the bias was influenced by whether the reference object had a containment function or a function that in some way changed the located object, and by whether or not the object afforded interaction with a limited set of objects.

2.5. INTEGRATING GEOMETRIC AND FUNCTIONAL FACTORS

The theories of the apprehension of spatial relations, presented in section 2.3., assume that the apprehension of projective relations depend on geometric factors only. Projective prepositions express relations of a strictly geometric nature according to these theories. However, the empirical results discussed in section 2.4. show that theories that only take geometric factors into account clearly are inadequate, as judgments about the applicability of projective prepositions are also influenced by functional factors. These studies have shown that the meanings of projective prepositions are not only concerned with schematic geometric relations between objects independent of their shapes, as has been suggested in early accounts of their meanings (see section 2.2.2.). Rather, the functional interaction between the objects is of importance as well. Judgments about how objects functionally interact in a specific situation depend on a number of sources of information (see the previous section). The perceived or inferred force-dynamic interaction between the objects is of importance and, in turn, judgments about force-dynamic patterns often presuppose knowledge about the functions of the objects involved in the interaction, knowledge about how they usually interact and information about how they interact in a specific situation. Such knowledge is largely determined by the shape and the parts of the objects, as parts of objects provide affordances which relate their shape to possible ways of interacting with them. A theory of the meanings of projective prepositions needs to take into account these multiple source of information. In this section, two such theories are presented.

2.5.1. An extension of the AVS-model

In an extension of the AVS-model (see section 2.3.5.), Regier et al. (2005) propose that perceptual and functional information jointly influence the vector representations of spatial templates. Functional influences clearly depend on the parts of the spatially related objects and their respective functions (see section 2.4.5.). Specifically, the functional bias reported by Carlson-Radvansky et al. (1999) appears to depend on aspects of the shape and the parts of the reference object. The extended version of the AVS-model deals with functional influences by taking the functional part of the reference object into account.

As discussed in section 2.3., the apprehension of projective relations involves a mapping between the conceptual and the spatial system by which the conceptual representation is matched with the spatial representation. This mapping is guided by frames of reference which reside in the spatial system (see section 2.3.2.). Information about the functions of objects, on the other hand, is represented in the conceptual system (Jackendoff, 1996). However, as mentioned in section, 2.3.1., lexical items and concepts are regarded as matchings between system specific information. Concepts might thus provide a link between conceptual information about the functions of objects and their spatial representations by specifying what part of the object is crucial for its function (Carlson, 2000). The fact that functional parts considered crucial for an object's function are detected faster suggests that more attention is paid to functional parts (see section 2.4.5.). According to the AVS-model, acceptability judgments about projectives depend on the alignment between the orientation of a vector sum and a reference orientation, such as upright vertical for *above* (see section 2.3.5.). As the vector sum depends on the weight of each vector, and that weight in turn depends on the amount of attention distributed across the reference object, the additional attention paid to the functional part of the object can be accounted for by increasing the weight of the vectors rooted in the functional part of the object. This will cause the vectors rooted in the functional part to contribute more to the vector summation, biasing its orientation towards upright vertical when the vectors are projected towards a point vertically in between the centre-of-mass of the reference object and its functional part, depending on the additional strength of the vectors rooted in the functional part. That is, the vector sum orientation will be aligned with upright vertical when the vectors are projected towards a point horizontally in between the centre-of-mass of the reference object and its functional part.

Importantly, this extended version of the AVS-model can account for the functional bias reported by Carlson-Radvansky et al. (1999); (see section 2.4.2.). By adjusting the additional weight paid to the functional parts of the objects, Regier et al. (2005) show that the model can account for the bias of both functionally related and unrelated objects.

2.5.2. The functional-dynamic framework

Although the extended version of the AVS-model can account for influences of the functional part of the reference object, it does not deal with the shape and the parts of the located object. Coventry & Garrod (2004) present further shortcomings with the model. The Coventry et al. (2001) study, presented in section 2.4.1., showed that ratings of vertical projectives are influenced by whether the threatening function is fulfilled, independent of geometric factors. For example, *over* was more acceptable in describing the relation between a man and an umbrella when the umbrella was protecting the man from rain than when it was not, although the geometric relation between the man and the umbrella was the same in both situations. According to Coventry & Garrod (2004), such influences on ratings cannot be accounted for by a singe geometric computation that takes into account an attentional bias of the functional part of an object, as suggested by the extended version of the AVS-model.

Rather, the functional influence on ratings has to depend on some separate computation, as it is independent of the geometry of the scene. The *functional-dynamic framework* (Coventry, 1998, 2003; Coventry & Garrod, 2004, 2005) is a theoretical framework that accounts for the meanings of spatial prepositions by taking separate computations into account. According to the framework, the meanings of spatial prepositions depend on the integration of information about the geometric relation between the objects and the perceived or inferred force-dynamic interaction between them, as well as knowledge about their functions and how they usually interact. As the framework aims at grounding the meaning of spatial prepositions in perceptual processes, geometric information is derived through the application of computational processes, or *geometric routines*, which compute geometric relations such as the computational process of the AVS-model (see section 2.3.5). Information about the force-dynamic interactions between objects, on the other hand, depends on the application of *dynamic-kinematic routines*, which are computational processes concerned with the force-dynamic interaction between objects.

When viewers define a relation between two objects in a certain situation, they construct a *situation model* that represents the integration and weighting of the geometric and force-dynamic information available in the scene. Situation models are mental surrogate representations of specific situations based on multiple sources of information that serve as interfaces between language and the world (Coventry, 1998; Coventry & Garrod, 2004, 2005; Garrod & Sanford, 1989). According to the framework, as the meanings of spatial prepositions often depend on the specific context, situation models are needed to explain the influence of context and multiple sources of information on acceptability judgments about spatial prepositions. The models are not to be seen as direct representations of a scene or a text, but rather as representations of the important features of a specific context. Importantly, the integration and weighting of geometric and force-dynamic information within a situation model is guided by knowledge about the function of the objects, knowledge about how these objects typically interact, and the functional relation between them in the specific context. Viewers attempt to construct the most informative model possible, that is, a model that supports the strongest inferences about the situation consistent with the information present in the scene itself. As spatial prepositions are associated with different geometric and force-dynamic constraints to varying degrees, the choice of preposition will depend on the integration and weighting of geometric and force-dynamic constraints of the situation model and, consequently, confidence in the preposition depend on the extent to which the model fits the actual scene. The meaning of a spatial preposition is thus ultimately situation-specific and depends on the weighted geometric and functional constraints of the situation model, that is, how a viewer construes a specific spatial scene.

For example, *over*, according to the framework, is perfectly acceptable for describing the relation between the toothpaste tube and toothbrush in figure 7 because knowledge about the functions of the objects in the scene primes a model which supports an inferred force-dynamic interaction between the objects. This interaction involves extracting toothpaste from the tip of the toothpaste tube onto the bristles of the toothbrush. Thus *over* is acceptable although the centre-of-mass of the toothpaste tube is misaligned with the centre-of-mass of the toothbrush because the force-dynamic constraints of the model fit the scene. With another object positioned above the toothbrush, on the other hand, such as the “x” used in the control images of the present study, *over* would be less acceptable for describing the relation. In this case, the model would only be concerned with the geometric relation between the objects, and the acceptability of *over* would only depend on the vertical alignment of the objects.

3. Method

3.1. EXPERIMENTAL DESIGN

3.1.1. Purpose and rationale

The overall purpose of the experiment is to examine if the comprehension of the Swedish vertical projectives *över*, *ovanför*, *nedaför* and *under* are influenced by functional factors in the same manner as the corresponding English projectives *over*, *above*, *under* and *below*, as reported in section 2.4. As Hörberg (2004) has shown that the process of reference frame adjustment is indeed influenced by functional factors for native Swedish speakers as has been reported for English speakers (Carlson-Radvansky & Tang, 2000); (see section 2.4.3.), the general prediction is that the comprehension of Swedish projectives is influenced by functional factors in a similar manner as their English counterparts. Importantly, functional influences are evaluated with respect to geometric influences and the assumption is that Swedish projectives are influenced by geometry as predicted by the AVS-model (see section 2.3.5.), which is the case for English projectives.

Functional influences are predicted to interfere with geometric influences in systematic ways, depending on characteristics of the functional interactions. As discussed in section 2.4.1., Carlson-Radvansky et al. (1999) showed that functional factors involving force-dynamics can influence the shape of the spatial template and that the shape of the template not only depend on the geometric factors predicted by the AVS-model. In their experiment, a region of acceptability around a reference object was probed, and the functional manipulation consisted in varying the position of the functional part of the reference object. The region of acceptability was influenced by the functional manipulation in that the peak ratings of the region varied as a function of the position of the functional part. Similarly, the rationale of the present experiment is to examine functional factors by investigating how they influence regions of acceptability.

The subjects' task is to rate, on a 7-grade Lickert-scale, how well they think sentences in Swedish of the form "The [located object] is [preposition] the [reference object]" match accompanying images showing a located object in a spatial relation to a reference object. Low ratings mean that the match between the sentences and the images is bad whereas high ratings mean that the match is good. The ratings can be regarded as a measure of how well the comprehension of a situation matches the meaning of a spatial expression (Coventry et al., 1994). That is, the rating is regarded as a measure of the goodness-of-fit between the spatial representation of the spatially related objects and the projective concept (see sections 2.3.4. and 2.3.5.). By varying the position of the located object, a crude region of acceptability is identified. On the one hand, the experiment contains a set of *experimental images* in which the objects are functionally related, and on the other, a set of *control images* lacking a functional relation. The control images contain the same reference object as the corresponding experimental images, but the located object is replaced with an "x" positioned at its centre-of-mass, henceforth referred to as a *control object*. Since control images are non-functional *per se*, ratings of these images are dependent on geometric factors only and the prediction is that their regions of acceptability will be in accordance with the predictions of the AVS-model (see section 2.3.5.). Functional influences are assessed by comparing the regions of acceptability of the experimental images with the regions of acceptability of the control images. As ratings of the latter depend on geometric influences only, any differences between ratings of experimental and control images have to be attributed to functional factors. According with the results of Carlson-Radvansky et al. (1999), functional relations are predicted to influence the regions in predictable manners that cannot be accounted for by the AVS-model. The dependent variable of the experiment, then, is the rating of the goodness-of-fit between the perceived spatial relation in the images and that of the prepositions. The patterns of the ratings are important as they represent regions of acceptability. The independent variables are the geometric and functional manipulations being made to the images as well as the type of preposition being tested. The variables are operationally defined below and the predictions of the experiment are presented in section 3.1.3.

3.1.2. Definitions of variables

The following variables concern geometric manipulations. As such, they affect all image types, experimental as well as control images.

Shape is defined as the shape of the reference object.

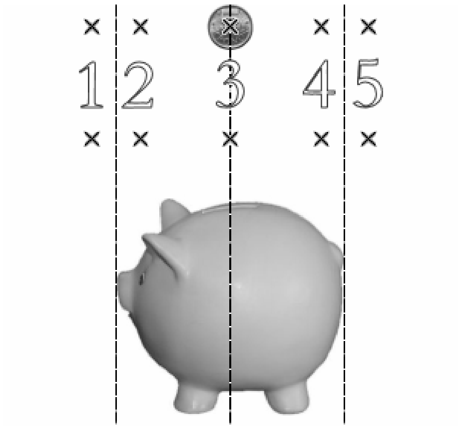
Position is defined as the horizontal position of the located object. The variable is correlated with the variables *Centre-of-mass Orientation*, *Proximal Orientation*, *Centre-of-mass Deviation* and *Proximal Deviation*.

Centre-of-mass Orientation is defined as the angle of an axis connecting the centre-of-mass of the reference object with the centre-of-mass of the located object. *Centre-of-mass Deviation* is defined as the angular deviation between the *Centre-of-mass Orientation* and upright vertical. *Proximal Orientation* is defined as the angle of an axis connecting the horizontally closest position of the reference object to the centre-of-mass of the located object. *Proximal Deviation* is defined as the angular deviation between the *Proximal Orientation* and upright vertical.

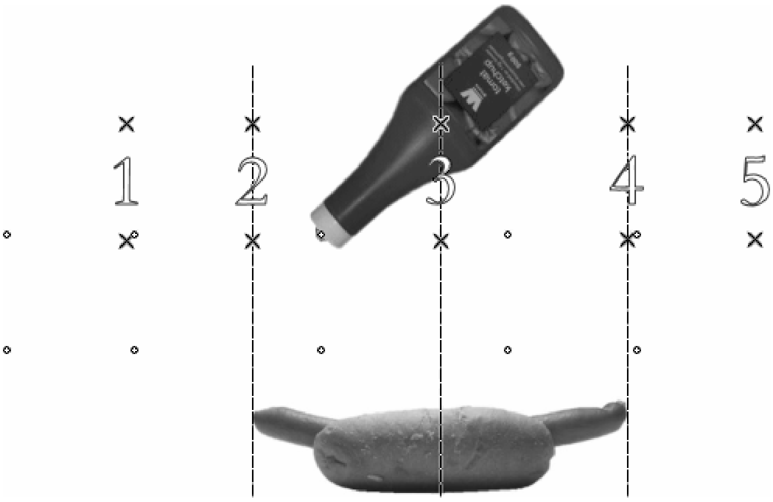
The variable *Position* has five values, each defined with respect to the reference object. Positions 1 and 5 on the one hand, and positions 2 and 4 on the other, are identical with respect to the relative distance between reference and located object. Positions 1 and 2 are located to the left of the reference object, whereas positions 4 and 5 are located to its right. At position 3, the centre of the located object is vertically aligned with the centre of the reference object. At this position, both the *Centre-of-mass* and *Proximal Deviation* is zero and it will henceforth be referred to as the *centre-of-mass aligned* position. Positions 2 and 4 differ between centre-of-mass aligned and centre-of-mass deviant images.[12] For centre-of-mass aligned images, the vertical edge of the located object farthest away from the centre of the reference object is vertically aligned with the edge of the reference object. For centre-of-mass deviant images, the centre of the located object is vertically aligned with the edge of the located object. At these positions, *Centre-of-mass Deviation* is positive while *Proximal Deviation* still is zero. They will henceforth be referred to as *centre-of-mass deviant* positions. At positions 1 and 5, the vertical edge of the located object closest to the centre of the reference object is vertically aligned with the edge of the reference object. At these positions, both *Centre-of-mass* and *Proximal Deviation* is positive. They will henceforth be referred to as *proximal deviant* positions. Examples of the positions for both centre-of-mass aligned and centre-of-mass deviant images are displayed in figure 8.

Distance is defined as the vertical distance between the reference and located object. The variable has two values; at the *Near* distance the vertical distance between the objects is 6.86 mm; at the *Far* distance the vertical distance between the objects is 25.91 mm.

[12] See the definition of the variable *Centre-of-Mass Interaction* for a description of these image types.



centre-of-mass aligned



centre-of-mass deviant

Figure 8. Examples of the positions of located objects in centre-of-mass aligned and in centre-of-mass deviant images. Each position is marked with an "x", and for the centre-of-mass deviant image, the secondary control positions are marked as dots.

The following variables concern functional manipulations. These variables only affect experimental images. The term *image set* refers to the total set of images concerned with a specific interaction, both prototypical as well as aprototypical. For example, the ten individual images of the hot dog and the ketchup bottle constitute an image set together with the ten individual images of the hot dog and the toothpaste tube.

Dynamics is defined as the threatening function that can potentially be fulfilled in an image. The function can be fulfilled at one or several specific positions, depending on the positions of the functional parts of the objects and the precision required to fulfil the interaction between the objects. These positions vary between image sets and will henceforth be referred to as *dynamic positions*. For instance, the dynamic position of the centre-of-mass aligned image in figure 8 is position 3, at which the coin is vertically aligned with the slot of the piggy bank. The dynamic positions of the centre-of-mass deviant image, on the other hand, are positions 3 to 5, at which the tip of the ketchup tube is vertically aligned with the hot dog.

Precision Interaction is defined as the number of dynamic positions within an image set. The variable has two values; *High precision Interactions* have only one dynamic position, i.e., the threatening function can only be fulfilled at one specific position. *Low precision Interactions* have more than one dynamic position, i.e., the function can be fulfilled at more than on specific position. The centre-of-mass aligned image in figure 8 is also a high precision image, as the threatening function can only be fulfilled at position 3, whereas the centre-of-mass deviant image is also a low precision image, as the threatening function can be fulfilled at positions 3 to 5.

Centre-of-mass Interaction is defined as the symmetry of the dynamic positions within an image set. The variable has two values; for *Centre-of-mass aligned Interactions*, the dynamic positions are symmetric: if a specific position is dynamic at one side, the corresponding position at the other side is necessarily dynamic as well. Also, if a *Centre-of-mass aligned Interaction* only has one dynamic position, i.e., is a *High precision Interaction*, this is necessarily the position which is vertically aligned with the centre-of-mass of the reference object, position 3, as in the centre-of-mass aligned image in figure 8. For *Centre-of-mass deviant Interactions*, the dynamic positions are asymmetric: the dynamic positions at one side are never the same as the dynamic positions at the other side, as in the centre-of-mass deviant image in figure 8. Furthermore, the dynamic position for *Centre-of-mass deviant Interactions* which are *High precision Interactions* is necessarily a position farthest to the left or right, position 1 or 5. Although the dynamic positions of centre-of-mass deviant images varied between the left and the right sides across the image sets used in the experiment, it is always the positions at the right side, i.e. positions 3 to 5, which are dynamic in the analyses of the results. The variables *Precision Interaction* and *Centre-of-mass Interaction* will be referred to together as *interaction variables.*

Prototypicality is defined as the functional relatedness of a reference object and a located object within an image set. The variable has two values; *Prototypical* images constitute a subset of an image set in which the reference object and located objects are functionally related. *Aprototypical* images constitute a subset of an image set in which the reference and located objects are functionally unrelated. However, the nature of the interaction is the same for both the prototypical and aprototypical images within a specific image set. As an example, the interaction between the hot dog and the ketchup bottle in figure 8 is a prototypical interaction. In the corresponding aprototypical images, the hot dog is replaced with a toothpaste tube. However, both the interaction between the ketchup bottle and the hot dog and the toothpaste tube and the hot dog involves pouring a substance onto the hot dog; both located objects have a threatening function of the same nature.

The last variables are concerned with control images only. These images are always non-functional, because the located objects in these images always consist of the control object.

Primary control is defined as a control image in which the control object is positioned at the centre-of-mass of the corresponding prototypical image. Primary control images correspond to each of the experimental images. *Primary control* is often referred to as *control.*

Secondary control is defined as a control image in which the control object is positioned at the centre of the functional part of the located object in the corresponding prototypical image, as illustrated in the centre-of-mass deviant image in figure 8. Within experimental groups 1 and 2, secondary control images correspond to centre-of-mass deviant images only. Within experimental groups 3 and 4, secondary control images correspond to centre-of-mass deviant/low precision images only.

3.1.3. Hypotheses

In general, predictions in four different areas are made within this work: how purely geometric factors influence ratings, how functional factors influence ratings, whether different prepositions are differentially influenced by these factors and finally how the functional part of the located object is influence ratings. In this section, the predictions of each of these areas are presented.

Influences of geometric factors are predicted to be in line with the predictions of the AVS-model. The crucial geometric manipulation is the position of the located object. For each reference object, ten strategic positions either above or below it are probed, yielding a crude region of acceptability. As a consequence, the centre-of-mass and the proximal orientation as well as the distance between the objects is varied. Also, as the control images contain various reference objects, the shape of the reference object is varied. These are the geometric factors of importance according to the AVS-model (see section 2.3.5.).

The model assumes that the shape of the reference object is of influence as the locations at which the vectors are rooted will vary depending on the shape of the object, which influences the orientation of the vector sum (Regier & Carlson, 2001). *Shape* is thus predicted to have a significant impact on control ratings in general.

The model further predicts that the acceptance of a projective relation is dependent on the proximal and the centre-of-mass orientations (Carlson et al., 2003; Regier, 1996; Regier & Carlson, 2001). *Centre-of-mass* and *Proximal Deviation* are therefore predicted to interact in the following way. Acceptability ratings should drop as a function of *Centre-of-mass Deviation*, and *Proximal Deviation* should further increase this drop in ratings. Specifically, the centre-of-mass aligned position is predicted to receive the highest ratings, followed by a drop in ratings of the centre-of-mass deviant positions and yet another drop of the proximal deviant positions. Also, the drop in ratings from the centre-of-mass deviant positions to the proximal deviant positions is predicted to be higher than the drop from the centre-of-mass aligned position to the centre-of-mass deviant positions, since *Proximal Deviation* only has an impact on ratings in proximal deviant positions. Given that the influence of *Centre-of-mass* and *Proximal Deviation* is linear and that both variables have a lowering effect on ratings, the effect of both variables taken together should be stronger than the effect of *Centre-of-mass Deviation* on its own.

The model also predicts an influence of distance, as the size of the attentional beam depends on the distance between the reference and located object, which affects the vector summation. A small distance between the objects results in a narrow beam which causes the orientation of the vector sum to approach proximal orientation, whereas a far distance yields a wider beam and, consequently, the vector sum orientation approaches centre-of-mass orientation (Regier & Carlson, 2001). Thus *Proximal Deviation* should have a higher influence on ratings than *Centre-of-mass Deviation* when the objects are close to each other. On the other hand, when the objects are further apart *Centre-of-mass Deviation* should have a higher impact on ratings than *Proximal Deviation*. *Distance* is thus predicted to interact with *Centre-of-mass* and *Proximal Deviation* in the following way. The drop in ratings from the centre-of-mass aligned position to the centre-of-mass deviant positions should be higher for *Far* ratings than for *Near* ratings. On the other hand, the drop in ratings from the centre-of-mass deviant positions to the proximal deviant positions should be higher for *Near* ratings than for *Far* ratings.

Influences of functional factors are predicted to be in line with earlier empirical results for English projectives, presented in section 2.4., and are assessed by comparing experimental ratings with control ratings.

As reported in section 2.4.1., a number of studies have shown that the comprehension of English vertical projectives is influenced by patterns of force-dynamics, and more specifically, by whether or not one of the spatially related objects fulfils a threatening or a protecting function (Carlson-Radvansky et al., 1999; Coventry & Mather, 2002; Coventry et al., 2001). In accordance with these results, the influence of the inferred force-dynamic interaction between the spatially related objects on acceptability ratings is examined by manipulating whether or not one of the related objects is fulfilling a threatening function. The force-dynamic interaction between two objects depends on the functions that the objects afford which in turn largely depend on the parts of those objects as function is highly correlated with shape (Glenberg & Kaschak, 2005; Tversky, 2005); (see section 2.4.5.). In order for two objects to interact functionally, they typically have to be positioned in a manner that affords their interaction; the functional parts of the objects have to be appropriately aligned as exemplified in section 2.4.5. Whether or not the threatening function is fulfilled depend on the position of the located object with respect to the reference object. Such fulfilment should entail an increase in ratings.

Experimental ratings of dynamic positions are therefore predicted to be rated significantly higher than the corresponding control ratings. The fulfilment of the threatening function in the experimental images should yield an increase in ratings absent in the corresponding control images. Also, experimental ratings of centre-of-mass deviant images are predicted to be rated significantly higher at the side of the dynamic position or positions than at the side that lacks dynamic positions. That is, positions 3 to 5 should be rated higher than positions 1 to 3. The fulfilment of the threatening function in all or one of the former positions should yield an increase in ratings absent in any of the latter positions. Such a difference can only be attributed to *Dynamics* since the geometry of both sides is identical in terms of *Proximal* and *Centre-of-mass Deviation*. However, such a difference between sides is predicted to be absent in ratings of control images as these lack dynamic positions since no threatening function is fulfilled in them.

Consistent with the idea that functional interactions largely depend on the shape and the parts of the related objects, Carlson & Covell (2005) provide evidence that functional influences depend on factors such as the position and shape of the functional part of the reference object and the precision required for the objects to interact. To further explore the influence of the shape of the objects and the positions of their functional parts, the position of the functional part of the reference object and the number of positions at which the threatening function can be fulfilled, that is, the precision required to fulfil the function, are manipulated. As these factors determine at which positions the threatening function is fulfilled, they are predicted to influence the regions of acceptability, and hence, *Precision* and *Centre-of-mass Interaction* are predicted to interact with *Position* in the following ways.

Experimental ratings of low precision images are predicted to be generally higher than ratings of high precision images since low precision images contain a number of dynamic positions whereas high precision images only contain one. Dynamic positions should in general be rated higher than undynamic positions since the threatening function is fulfilled at these positions, and hence, the overall rating of low precision images should be higher. This difference between low and high precision images should be absent in ratings of the corresponding control images as they lack dynamic positions.

Experimental ratings of centre-of-mass deviant images are predicted to be rated significantly higher at the side of the dynamic position or positions than at the side that lacks dynamic positions. Specifically, positions 3 to 5 should be rated higher than positions 1 to 3. The fulfilment of the threatening function at one or all of the former positions should yield an increase in ratings absent in any of the latter positions. This difference between sides is predicted to be absent in ratings of control images as they lack dynamic positions.

Concerning centre-of-mass aligned images only, the following predictions are made. The influence of *Centre-of-mass Deviation* at the centre-of-mass deviant positions should be weaker for low precision images than for high precision images since these positions are dynamic for the former but not for the latter. As the threatening function is fulfilled at these positions in the low precision images, ratings of them should increase. Specifically, centre-of-mass deviant positions are predicted to be rated higher for low precision images than for high precision images. Also, the drop from the centre-of-mass aligned position to the centre-of-mass deviant positions is predicted to be higher for high precision images than for low precision images. On the other hand, proximal deviant positions should not be rated significantly different for low and high precision images since these positions are undynamic for both image types. This, in turn, should entail a higher drop in ratings from the centre-of-mass deviant positions to the proximal deviant positions for low precision images than for high precision images. These differences are predicted to be absent in the control ratings, as control images lack dynamic positions.

Finally, the following predictions concerning experimental ratings of centre-of-mass deviant images are made. Ratings of the positions which are dynamic for low precision images but undynamic for their high precision equivalents are predicted to be higher for the former than for the latter. That is, position 3 and 4 are predicted to be rated higher for low precision images than for high precision images. This difference is predicted to be absent in the control ratings, since control images lack dynamic positions.

As acceptability judgments about English vertical projectives have been shown to be sensitive to knowledge about whether or not the spatially related objects are functionally related (Carlson-Radvansky et al., 1999; Coventry et al., 1994; Coventry et al., 2001); (see section 2.4.2.), the influence of such knowledge on acceptability ratings is examined. This is done by manipulating whether or not the objects in the scene are functionally related. Previous studies have shown that functional influences on acceptability judgments about English projectives are stronger when the objects are functionally related than when they are unrelated and the prediction is that acceptability judgments about Swedish projectives are influenced in the same way. Dynamic ratings are thus predicted to be higher for prototypical images than for aprototypical images.

The experiment aims at exploring the influence of the functional part of the located object on ratings. The extended version of the AVS-model can account for the influence of the functional part of the reference object, but assumes that the located object schematizes to a point (see section 2.5.1.). However, as noted by Carlson & Covell (2005), the functional interaction between two objects do not only depend on the affordances of the reference object, but also on the affordances of the located object, which in turn depend on its shape and parts (see section 2.4.5.). According to the model, functional influences are accounted for by extra distribution of attention paid to the relevant functional part of the reference object. However, as judgments about whether a functional interaction is fulfilled depend also on the functional part of the located object, attention should also be paid to its functional part, and not only to its centre-of-mass, as assumed by the model. A final purpose of the experiment is to investigate the influence of the functional part of the located object. This is done in two ways.

First, the extended version of the AVS-model can account for a bias in ratings towards the functional part of the reference object when that part is misaligned with the centre-of-mass of the object and its location thus is asymmetric. The model predicts that ratings will be higher at the side of the functional part than at the opposite side. However, the model cannot predict a bias when the functional part of the reference object either is aligned with its centre-of-mass, or extends completely along its upper side, so that its location is symmetric. However, although the location of the functional part of the reference object is symmetric, an asymmetry of the functional part of the *located* object is predicted to cause a bias in ratings towards the side of its functional part. That is, the low precision versions of the centre-of-mass deviant images are predicted to cause a bias in ratings at the side of the dynamic positions. An example of such an image is the centre-of-mass deviant image in figure 8. As the functional part of the reference object, the top of the hot dog onto which ketchup is poured, extends completely along its upper side, a bias in ratings cannot be accounted for in terms of extra distribution of attention paid to one of the sides of the reference object, as the distribution of attention has to be equally distributed along the upper side of the object. Thus any bias in ratings towards the side of the functional part of the located object has to be attributed to characteristics of the located object, and presumably the location of its functional part. Thus if low precision/centre-of-mass deviant images are rated significantly higher at the side of the dynamic positions than at the side that lacks dynamic positions indicates that ratings are influenced by the functional part of the located object.

Secondly, secondary control images are included in the experiment. In the secondary control images, the control object is located at the centre of the functional part of the corresponding located object, instead of at its centre-of-mass. Thus ratings of both the position of the centre-of-mass of the located object and ratings of the position of the centre of its functional part are obtained. By collapsing primary and secondary control ratings, an estimate of the joint influence of both of these locations on ratings, further referred to as a *control estimate,* is obtained. If ratings of experimental images are influenced by attention paid to the position of the centre of the functional part of the located object, and not only to the position of its centre-of-mass, the patterns of the experimental ratings should match the patterns of the control estimates. That is, the regions of acceptability of the experimental images should match the estimated regions of acceptability of the control estimates.

Finally, acceptability judgments about the prepositions examined in the experiment are predicted to be differentially influenced by functional factors, as a number of studies have shown is the case for the corresponding English prepositions (Coventry & Mather, 2002; Coventry et al., 2001; Hörberg, 2004); (see section 2.4.4.). Specifically, Coventry et al. (2001) and Coventry & Mather (2002) have shown that acceptability judgments about *over* and *under* are influenced by functional factors to a greater extent than *above* and *below*. One purpose of the experiment is to investigate if judgments about the corresponding Swedish prepositions are influenced in a similar manner. As Hörberg (2004) has shown that Swedish projectives are differentially influenced by functional factors in the process of reference frame selection (see section 2.4.3.), the prediction is that this is the case: *över* and *under* are predicted to be influenced by functional factors to a greater extent than *ovanför* and *över.* The difference between ratings of experimental images and ratings of control images should be higher for ratings of *över* and *under* than for ratings of *ovanför* and *nedanför*, as functional influences only are available in experimental images.

3.1.4. Design

The experiment is divided into four experimental groups. Each group is concerned with one primary preposition for which both experimental and control images are used. Within each group, a secondary preposition is included for variety, for which only the experimental images are used. Finally, within each group a small set of fillers are included. These filler images are concerned with the two other prepositions being tested in the experiment. However, the results of the filler ratings were excluded from the final analysis. The purpose of the fillers was to keep the subjects attentive to the task at hand and to show if individual subjects complied with the instructions. They are further discussed below. The prepositions are divided between the groups in the following ways:

Group 1: Primary preposition: *ovanför*; Secondary preposition: *nedanför*; Fillers: *över* and *under*
Group 2: Primary preposition: *över*; Secondary preposition: *under*; Fillers: *ovanför* and *nedanför*
Group 3: Primary preposition: *nedanför*; Secondary preposition: *ovanför*; Fillers: *över* and *under*
Group 4: Primary preposition: *under*; Secondary preposition: *över*; Fillers: *ovanför* and *nedanför*

Groups 1 and 2 together are occasionally referred to as the *ovanför/över* set whereas groups 3 and 4 together are at times called the *nedanför/under* set. The images used in the experiment differ between each prepositional pair. That is, the *ovanför-över* pair has one set of images consisting of two different subsets, whereas the *nedanför-under* pair has a different set, consisting of two different subsets. This was done to ensure that the reference object always is the biggest one and/or the most stable one (see section 2.1.4.). A list of the objects used in each set is available in appendix 1.

The design of the experimental image groups is displayed in table 1. Each experimental image group is divided into two sets, each set being concerned with all of the variables of the experiment. Two sets were used to increase the validity of the experiment. Each set consists of four different image sets, each of them corresponding to the possible combinations of the interaction variables *Precision Interaction* and *Centre-of-mass Interaction*, defined in section 3.1.2. Each image set is divided into a *prototypical* and *aprototypical* set, in accordance with the definition in section 3.1.2. Each of these sets consists of 10 separate images, in which the located object is positioned at position 1 to 5, at both a *Near* and a *Far* distance from the located object, according to the definitions in section 3.1.2. The total number of images within an experimental image group thus add up in the following way: 2 (*Distance*) × 5 (*Position*) × 2 (*Prototypicality*) × 2 (*Centre-of-mass Interaction*) × 2 (*Precision Interaction*) × 2 (*Set*), yielding a total of 160 images.

Table 1. The distribution of conditions for experimental images. Each position (1-5) constitutes a separate value, each divided as a function of *Distance*.

Set	Precision	Centre-of-mass	Prototypicality	Position	Distance
Set 1	Low	Aligned	Prototypical	Position 1-5	Near
					Far
			Aprototypical	Position 1-5	Near
					Far
	Low	Deviant	Prototypical	Position 1-5	Near
					Far
			Aprototypical	Position 1-5	Near
					Far
	High	Aligned	Prototypical	Position 1-5	Near
					Far
			Aprototypical	Position 1-5	Near
					Far
	High	Deviant	Prototypical	Position 1-5	Near
					Far
			Aprototypical	Position 1-5	Near
					Far
Set 2	Low	Aligned	Prototypical	Position 1-5	Near
					Far
			Aprototypical	Position 1-5	Near
					Far
	Low	Deviant	Prototypical	Position 1-5	Near
					Far
			Aprototypical	Position 1-5	Near
					Far
	High	Aligned	Prototypical	Position 1-5	Near
					Far
			Aprototypical	Position 1-5	Near
					Far
	High	Deviant	Prototypical	Position 1-5	Near
					Far
			Aprototypical	Position 1-5	Near
					Far

The design of the control image groups is displayed in table 2. Each control image group is divided into eight sets, each set corresponding to an image set within the experimental images, and henceforth referred to as *control sets*. Each control set uses the reference object from the corresponding image set to test the influence of *Shape*, as defined in 3.1.2., on control ratings. Each set is further concerned with the rest of the geometric variables. However, not every control set includes secondary control images.

Only control sets corresponding to centre-of-mass deviant image sets can include secondary control images, because only centre-of-mass deviant images uses located objects for which the functional part deviates from centre-of-mass. For the *nedanför* and *under* control sets, only the control sets corresponding to high precision/centre-of-mass deviant image sets include secondary control images. The reason for this is that it was difficult to come up with image sets for these groups in which it was the located object that had a functional part deviating from centre-of-mass, a problem further discussed in section 5.3.1. Both primary and secondary control sets consist of 10 separate images, in which the located object is positioned at position 1 to 5, at both a *Near* and a *Far* distance from the located object, according to the definitions in section 3.1.2. The total number of images within each of the *ovanför* and *över* control image groups thus add up in the following way: *Primary* (2 (*Distance*) × 5 (*Position*) × 8 (*Shape*)) + *Secondary* (2 (*Distance*) × 5 (*Position*) × 4 (*Shape*)), yielding a total of 120 images. The total number of images within each of the *nedanför* and *under* control image groups, on the other hand, add up in the following way: *Primary* (2 (*Distance*) × 5 (*Position*) × 8 (*Shape*)) + *Secondary* (2 (*Distance*) × 5 (*Position*) × 2 (*Shape*)), yielding a total of 100 images.

Table 2. The distribution of conditions for control images, for each prepositional pair. Each position (1-5) constitutes a separate value, each divided as a function of *Distance*. Some of the control sets do not contain secondary control images, as illustrated by the grey fields.

ovanför* and *över				***nedanför* and *under***			
Shape	**Control**	**Position**	**Distance**	**Shape**	**Control**	**Position**	**Distance**
1	Primary	Position 1-5	Near	1	Primary	Position 1-5	Near
			Far				Far
2	Primary	Position 1-5	Near	2	Primary	Position 1-5	Near
			Far				Far
	Secondary	Position 1-5	Near				
			Far				
3	Primary	Position 1-5	Near	3	Primary	Position 1-5	Near
			Far				Far
4	Primary	Position 1-5		4	Primary	Position 1-5	Near
			Far				Far
	Secondary	Position 1-5	Near		Secondary	Position 1-5	Near
			Far				Far
5	Primary	Position 1-5	Near	5	Primary	Position 1-5	Near
			Far				Far
6	Primary	Position 1-5	Near	6	Primary	Position 1-5	Near
			Far				Far
	Secondary	Position 1-5	Near				
			Far				
7	Primary	Position 1-5	Near	7	Primary	Position 1-5	Near
			Far				Far
8	Primary	Position 1-5	Near	8	Primary	Position 1-5	Near
			Far				Far
	Secondary	Position 1-5	Near		Secondary	Position 1-5	Near
			Far				Far

Each experimental group contains a small set of filler images. The filler images are made up of four groups with 10 images in each group, henceforth referred to as *filler sets*, making a total of 40 filler images per experimental group. Half of the images within a filler set are concerned with the *ovanför-över* pair, whereas the other half are concerned with the *nedanför-under* pair. Each filler set contains mostly functionally related objects, for which the located objects are located in dynamic or close to dynamic positions.

However, in the first filler set, the name of the reference object has been switched with the name of the located object in the sentences. For example, in one image a ketchup pump served as the reference object and a hot dog as the located object, positioned in a dynamic position below the ketchup pump. However, the sentence below the picture read *The ketchup pump is under the hot dog*. Within the second filler set, the prepositions have been switched. For instance, the sentence below an image showing a toothbrush above a toothpaste tube read *The toothpaste tube is under the toothbrush* instead of *The toothpaste tube is over the toothbrush*. Within the third filler set, the name of the located object is the name of a functionally related object. The sentence below a picture that showed a piece of trash above a coffee mug read *The sugar cube is above the coffee mug*. Within the fourth and final filler set the name of the reference object is the name of a functionally related object. Thus the sentence below a picture that showed a wine carafe below a ketchup pump read *The wine carafe is below the wine barrel*.

The purpose of the filler images is threefold. First, one purpose is to make the subjects attentive to the task at hand. As the sentences in the filler images were inaccurate descriptions of the images, subjects had to pay attention in order to spot these inaccuracies. More specifically, different stages of the apprehension process needed to be processed in order to spot the inaccuracies (see section 2.3.2.). To spot the inaccuracy of the first filler sets, subjects had to correctly match the first argument of the spatial expression with the located object and the second argument with the reference object. That is, the objects in the spatial representation had to be appropriately indexed as the arguments of the conceptual representation of the spatial expression. To spot the inaccuracy of the second set, subjects had to match the spatial relation between the objects with the preposition at hand. Thus they needed to assign the appropriate projective predicate to the relevant base axis of the reference frame of the reference object. To spot the inaccuracies in the third and fourth set, subjects had to match either the first argument of the spatial expression with the located object, or the second argument with the reference object. That is, they needed to correctly index either the located object or the reference object in the scene as the first or the second argument of the conceptual representation of the spatial expression, respectively. Secondly, the fillers show if a specific subject complied with the task. Subjects that were inattentive to the task were expected to miss the inaccuracies of the filler images, and consequently, give high or medium ratings to them. Thirdly, the filler images give a broader verity to the images within the experiment. The purpose of this was to make the task more stimulating and less routine-like.

The total number of images for groups 1 and 2 thus add up to 160+160+120+40 = 480 images, whereas the total number of images for groups 3 and 4 add up to 160+160+100+40 = 460 images. Pilot studies showed that the average time a subject spent on the rating of one image was 6 seconds. Therefore, the average time the subjects would spend on the experiment was estimated to roughly 45 minutes.

3.2. SUBJECTS

A total of 72 subjects participated in the experiment, with 18 subjects in each group. Eight subjects were friends of the author and conducted the experiment in his home. These subjects received no direct remuneration for participating; however some of them were treated to a meal once they had finished the experiment. The remaining 64 subjects conducted the experiment at the Department of Linguistics at the Stockholm University. They were either students or employees at the university, many of them active at the department. Most of these subjects automatically participated in a draw for cinema vouchers (each of them worth 100 SEK). The purpose of the lottery was to encourage participation. Many of the subjects were further encouraged by being offered coffee and a snack while performing the experiment.

Five subjects stated that Swedish was not their native language. One further subject claimed to be dyslexic and reported having difficulties at times. However, the data reported by these subjects was included in the overall result and was treated as the rest of the data. The age of the subjects had a median value of 26 years, with a quartile deviation of 6.63. The age distribution was positively skewed, with a skewness of 1.65. Only 30% (22 subjects) were male, showing a skewed sex distribution as well.

3.3. MATERIAL AND STIMULI

3.3.1. Software

The software used to run the experiment was written by the author in the script-based language PHP.[13] The PHP-scripts were written for Microsoft Internet Explorer, but were also compatible with Netscape Navigator. The scripts together with the pictures of the objects and the control images were installed at a server at the Department of Linguistics at the Stockholm University, and could be accessed at some of the computers at the department, connected to the server. The scripts and pictures were also installed at the private computer of the author and could be accessed at this computer. Results were automatically saved on the servers in a SQL database through MySQL when the experiment was conducted.

3.3.2. Object images

The objects used in the experiment, listed in appendix 1, were photographed one by one with a digital camera and further processed in Corel Paint Shop Pro v.10.00. The objects in the digital photos were cut out from the background, matched in size and rotated to the appropriate orientation. Primary and secondary control images were also created. Primary control images correspond to each of the located objects. They were created by placing the control object at a position which was estimated to be the same as the centre-of-mass of the corresponding located object. Secondary control images correspond to the located objects in the centre-of-mass deviant images in groups 1 and 2 and the located objects in the high precision/centre-of-mass deviant images in groups 3 and 4. These were created by placing the control object at a position which was estimated to be the same as the centre of the functional part of the corresponding located object.

[13] Thanks to Rickard Franzén at the Department of Linguistics at the Stockholm University for his help. Without his help, this would never have been possible.

3.3.3. Presentation of stimuli

The experiment consisted of a start page and a series of experimental pages, containing each experimental image constructed out of the object pictures discussed in the previous section, in accordance with the variables defined in section 3.1.2.

The start page contained a framed box with instructions. An illustration of the start page with the instructions translated to English is available in appendix 2. Roughly, the instructions informed the subjects that the experiment would take about 45 minutes to perform and that the task was to rate on a 7-grade scale how well a series of sentences matched accompanying images. The instructions further said that the scale went from 1 to 7 where 1 meant that the sentence did not match the image at all whereas 7 meant that the sentence matched the image very well. Also, a graphical illustration of the scale, displayed in appendix 2, was shown to assist their understanding of the scale ratings. Furthermore, the subjects were instructed to press key 1 to 7 on the keyboard to rate a specific image and to be careful since it was impossible to redo a rating.

The subjects that performed the experiment at the Department of Linguistics were further informed that they had the chance to win a cinema voucher worth 100 SEK and that they would be informed if they had won as soon as they had finished the experiment. Finally, the subjects were told that there would be a test run before the actual experiment started, to get acquainted with the procedure. Below these instructions, the subjects were asked to state their age, sex and whether they had Swedish as their native language.

The layout of the experimental pages was designed in the following way. At the top of the page, a framed box contained a text that requested the subjects to rate how well they thought the text below the image matched the image in question, in accordance to the scale at the bottom of the page. Below this box, the actual experimental image was shown in accordance with the experimental condition being tested. The sentence to be rated was written directly below the experimental image. On the bottom of the page, a framed box with a graphical illustration of the scale similar to the illustration at the start page was located. An example of one of the experimental pages is shown in appendix 3.

The order of the images differed between groups 1 and 2 on the one hand, and groups 3 and 4 on the other, but was the same between the subjects of groups 1 and 2 and the subjects of groups 3 and 4. Hence no counterbalancing of the stimuli was made, a deficiency of the experiment further discussed in section 5.3.2.

The order of the images in all groups was decided in the following way. Individual images were picked out at random from each image set, control set and filler set. Two images were picked out from each image set, one prototypical and one aprototypical. From the control sets containing both primary and secondary control images, one of each type was picked out. One image was picked out from control sets consisting of only primary control images. Finally, one image was picked out from each of the filler sets. These images made up groups of images with one image from each experimental condition, each group consisting of 48 individual images for experimental groups 1 and 2 on the one hand and 46 individual images for experimental groups 3 and 4 on the other. The individual images within each group were further randomized and the groups were put together in an ordered fashion. This procedure ensured a balanced distribution of conditions across the image sequence.

3.3.4. Sentences

As mentioned in section 2.1.3., English as well as Swedish locative expressions are constructed using a complement or adjunct prepositional phrase. Locative expressions involving projective prepositions establish the location of a located object with respect to a reference object by expressing how the located object is spatially related to the reference object (see section 2.1.4.). The purpose of the sentences in the experiment is to describe the spatial relation between the objects in the pictures. Therefore, predicative sentences with a copula having a purely grammatical function were used (see section 2.1.3.), that is, sentences of the form “The [located object] is [preposition] the [reference object]” (see section 3.1.1.). Such sentences, with the syntactic form [$_{S}$ [$_{NP}$ The located object] [$_{VP}$ is [$_{PP}$ above [$_{NP}$ the reference object]]]] express the spatial relation between the located and the reference object by predication, i.e., by ascribing the property of being spatially located above the reference object to the located object.

3.4. PROCEDURE

The experiment was conducted in the following way. 64 subjects were drafted during a two-week period and could choose freely when to perform the experiment from different experimental sessions, held at predetermined dates and hours in the two-week period. The number of subjects at each session varied between one and twelve and a few sessions were cancelled because of lack of participation. The subjects performed the experiment at a computer room at the Linguistics Department at the Stockholm University. Some of the subjects were instructed to sit down by a computer at which the PHP-script had been run in advance. Others had to enter the correct address themselves in Internet Explorer, as displayed on a whiteboard, to access the script. The subjects performing the experiment during the second week were offered coffee or tea as well as a snack while performing the experiment. The eight subjects who performed the experiment at the home of the author were instructed to sit down at the computer were the PHP-script had been run in advance. Most of these subjects were treated to a nice meal once they had finished the experiment.

Once the experiment was started, the start page described in section 3.3.3. was displayed. All of the subjects were verbally instructed to follow the instructions shown on this page. By clicking a button at the bottom of the page a test run of the experiment was started. The test run consisted of ten experimental pages, as describe in section 3.3.3., containing test images to be rated. Once the subjects had finished the rating of the test images, another page with instructions appeared. These instructions informed the subjects that the test run was over and that the actual experiment was about to start. Once again the subjects were asked to be careful when choosing a key since it was impossible to redo a rating. The actual experiment, containing the series of experimental pages, was started by clicking a button below these instructions.

When the experiment was finished, a final information page appeared. The subjects were informed that the experiment was over and whether they had won a cinema voucher or not. Finally, they were thanked for their participation.

4. Results

Throughout the results chapter, an α of .05 is assumed. Prototypical ratings taken together with aprototypical ratings are referred to as *Experimental* ratings.

4.1. GEOMETRIC INFLUENCES

For the ratings of the control images, two 8 (*Shape*) × 5 (*Position*) × 2 (*Distance*) × 2 (*Preposition*) ANOVAs were conducted, with *Shape*, *Position* and *Distance* as within-subjects factors and *Preposition* as a between-subjects factor, the first conducted for the *ovanför* and *över* groups, and the second for the *nedanför* and *under* groups. Within these models, the secondary control ratings are excluded. The results of these ANOVAs are displayed in table 3.

Table 3. Results of two mixed ANOVAs for ratings of control images only.

	Source	***ovanför* and *över***					***nedanför* and *under***				
		***df*1**	***df*2**	***MS***	***F***	***p***	***df*1**	***df*2**	***MS***	***F***	***p***
Within groups	Shape	7	238	32.19	24.02	.001***	7	238	14.17	6.35	.001***
	Position	4	136	808.74	77.36	.001***	4	136	1007.15	89.91	.001***
	Distance	1	34	10.88	4.41	.043*	1	34	3.20	3.15	.085 *ns*
	Shape × Position	28	952	2.94	3.25	.001***	28	952	25.12	21.64	.001***
	Shape × Distance	7	238	2.40	2.98	.005**	7	238	1.33	2.29	.028*
	Position × Distance	4	136	2.19	2.91	.024**	4	136	0.75	1.15	.337 *ns*
Between groups	Preposition	1	34	2120.08	16.72	.001***	1	34	0.40	0.00	.953 *ns*
	Shape × Preposition	7	34	1.04	0.78	.605 *ns*	7	34	3.06	1.37	.218 *ns*
	Position × Preposition	4	34	13.54	1.30	.275 *ns*	4	34	5.46	0.49	.745 *ns*
	Distance × Preposition	1	34	12.67	5.14	.03**	1	34	1.70	1.68	.204 *ns*

Note: *ns* = non-significance, $p > .05$; * $p < .05$; ** $p < .01$; *** $p < .001$

4.1.1. *Shape*

As seen in table 3, *Shape* has a significant impact on ratings of the control images in the *ovanför*/*över* set as well as in the *nedanför*/*under* set. For both sets, there are also significant interactions between *Shape* and *Position* as well as between *Shape* and *Distance*.

These interactions show that the angular deviation between the axis connecting the objects and the vertical axis of the reference object as well as the distance between the reference object and the control object had different impacts on ratings depending on the shape of the reference object.

4.1.2. *Position*: *Centre-of-mass* and *Proximal Deviation*

Unsurprisingly, *Position* has a significant influence on ratings for both sets, as shown in table 3. There are also interactions between *Position* and *Shape*, as mentioned in the previous section, and between *Position* and *Distance,* further discussed in 4.1.3. There is no significant interaction between *Position* and *Preposition*, showing that the influence of *Position* did not differ between prepositions. The general influence of *Position,* averaged across prepositions, is shown in figure 9. In general, ratings are at their highest when the objects are vertically aligned. Ratings then drop as a function of *Centre-of-mass* and *Proximal Deviation*. However, as seen in figure 9, the joint influence of *Centre-of-mass* and *Proximal Deviation* appear to reduce this drop, rather then increasing it, as the AVS-model predicts. That is, the first drop in ratings from the centre-of-mass aligned position to the centre-of-mass deviant positions appears to be higher than the second drop from the centre-of-mass deviant positions to the proximal deviant positions.

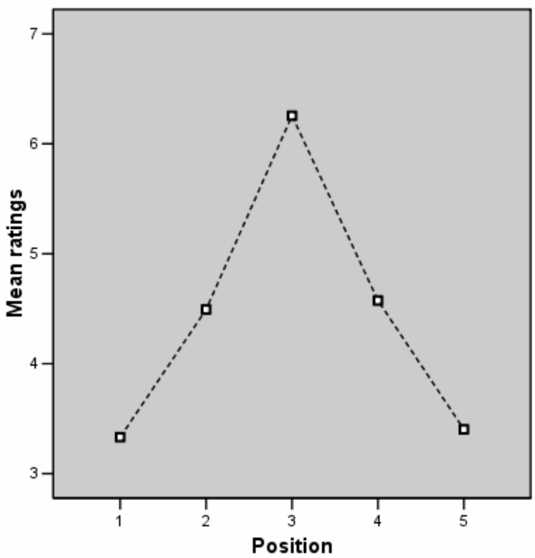


Figure 9. Mean ratings for control images as a function of *Position*. Position 3 is the centre-of-mass aligned position, positions 2 and 4 are the centre-of-mass deviant positions and positions 1 and 5 are the proximal deviant positions.

To determine if the first drop in ratings is higher than the second, the following procedure was used. Since *Centre-of-mass Deviation* is correlated with *Proximal Deviation*, these variables could not function as separate factors within the ANOVA models. Instead, for each preposition and thereby for each group, Paired Samples *t*-tests were conducted comparing the difference between ratings of the centre-of-mass aligned position and the centre-of-mass deviant positions and the difference between the centre-of-mass deviant and proximal deviant positions, respectively. These differences and the results of the *t*-tests are displayed in table 4. Across and within groups, except for the *under* group, the first difference is significantly bigger than the second. However, in a majority of the images the distance between the centre-of-mass aligned position and the centre-of-mass deviant positions is higher than the distance between the centre-of-mass deviant positions and the proximal deviant positions. Overall, the first distance accounts for 58% of the total distance between the centre-of-mass aligned position and the proximal deviant positions, whereas the second distance only accounts for 42% of the total distance. Thus it might be the case that the drop in ratings from the centre-of-mass deviant positions to the proximal deviant positions is *proportionally* higher than the drop from the centre-of-mass aligned position to the centre-of-mass deviant positions.

Table 4. Mean differences, mean percentual drop per mm and results of Paired Samples *t*-tests per group and in total.

	Group	**Mean and standard deviation**		**Paired Samples *t*-tests, 1-tailed**		
		Difference 1	**Difference 2**	***t***	***df***	***p***
Differences	**Group 1 - *ovanför***	1.47 (1.73)	1.05 (1.48)	4.14	575	.001***
	Group 2 - *över*	1.97 (1.94)	1.28 (1.61)	6.23	575	.001***
	Group 3 - *nedanför*	1.67 (1.77)	1.36 (1.61)	2.91	575	.004**
	Group 4 - *under*	1.56 (1.91)	1.72 (1.98)	1.56	575	.119 *ns*
	Total	1.67 (1.85)	1.35 (1.7)	5.47	2303	.001***
	Group	**Mean and standard deviation**		**Paired Samples *t*-tests, 1-tailed**		
		% drop/mm 1	**% drop/mm 2**	***t***	***df***	***p***
Percentual drop per mm	**Group 1 - *ovanför***	6.58% (2.09%)	10.44% (4.44%)	6.01	31	.001***
	Group 2 - *över*	10.22% (4.9%)	14.14% (8.55%)	5.26	31	.001***
	Group 3 - *nedanför*	4.72% (1.16%)	8.36% (4.89%)	4.26	31	.001***
	Group 4 - *under*	9.64% (5.52%)	13.83% (12.24%)	1.96	31	.06 *ns*
	Total	7.78% (4.45%)	11.69% (8.42%)	4.9	127	.001***

Note: *ns* = non-significance, $p > .05$; * $p < .05$; ** $p < .01$; *** $p < .001$

Across subjects, the percentual drop in ratings per millimetre was calculated for each image. This was done for both drops; given that the drops are linear, the drop per mm should be significantly higher for the second drop than for the first if the second drop is proportionally higher than the first. The means of these percentages per group as well as the total means are displayed in table 4. Across and within groups, except for the *under* group, the drop per mm is significantly higher for the second drop than for the first, showing that *Proximal Deviation* increases the drop in ratings as predicted by the AVS-model.

4.1.3. *Distance*

As seen in table 3, *Distance* only has a significant impact on ratings of the control images for the *ovanför/över* set and no impact for the *nedanför/under* set. For the first set, there is also a significant interaction between *Distance* and *Preposition* as well as between *Distance* and *Position*. For both sets there is a significant interaction between *Distance* and *Shape*. However, further analyses consisting of four 8 (*Shape*) × 5 (*Position*) × 2 (*Distance*) ANOVAs, fully within each group, yielded inconclusive results. There is a significant effect of *Distance* for the *ovanför* and the *under* groups [Group 1: $F_{1, 17} = 8.75$, $p < .001$; Group 4: $F_{1, 17} = 4.65$, $p < .05$] but not for the *över* and the *nedanför* groups [Group 2: $F_{1, 17} = 0.02$, $p = .903$; Group 3: $F_{1, 17} = 0.18$, $p = .736$]. There is a significant interaction between *Distance* and *Shape* for the *ovanför* and *under* groups [Group 1: $F_{7, 119} = 2.11$, $p < .05$; Group 4: $F_{7, 119} = 2.26$, $p < .05$] but not for the *över* and the *nedanför* groups [Group 2: $F_{7, 119} = 1.34$, $p = 0.237$; Group 3: $F_{7, 119} = 1.03$, $p = 0.417$]. There is also a significant interaction between *Distance* and *Position* for the *ovanför* and *nedanför* groups [Group 1: $F_{4, 68} = 3.82$, $p < .01$; Group 3: $F_{4, 68} = 2.62$; $p < .05$] but not for the *över* and *under* groups [Group 1: $F_{4, 68} = 0.87$, $p = 0.487$; Group 3: $F_{4, 68} = 1.12$, $p = 0.352$].

The effect of *Distance* is significant for the control images across all four groups, as shown by a 8 (*Shape*) × 5 (*Position*) × 2 (*Distance*) × 4 (*Preposition*) ANOVA (*Shape*, *Angle* and *Distance* within, *Preposition* between) [$F_{1, 68} = 7.44$, $p < .05$]. Across all four groups, there are also significant interactions between *Distance* and *Preposition* [$F_{3, 68} = 2.97$, $p < .001$], *Distance* and *Shape* [$F_{7, 476} = 3.12$, $p < .01$], as well as between *Distance* and *Position* [$F_{4, 272} = 3.84$, $p < .01$]. The interaction between *Distance* and *Position* across groups is displayed in figure 10. In general, proximal deviation ratings are higher when the control object is at a *Far* distance than at a *Near* distance, in line with the predictions of the AVS-model. However, as noted above, the influence of *Distance* is not significant within all groups.

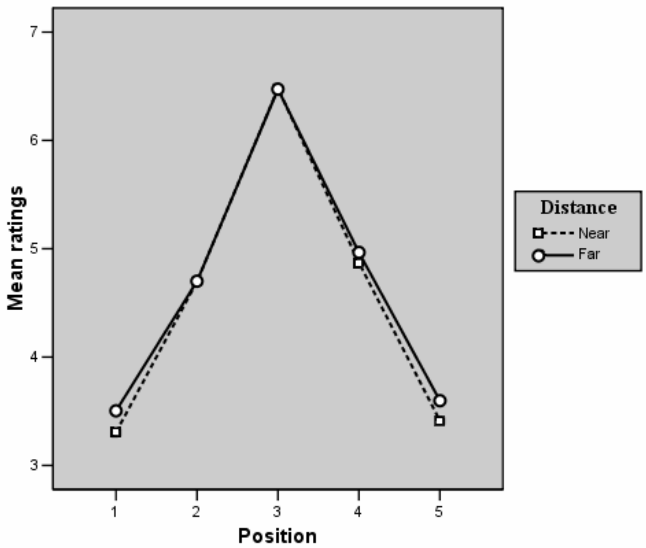


Figure 10. Mean ratings of control images, as a function of *Distance*.

4.2. FUNCTIONAL INFLUENCES

Across groups, a 2 (*Precision Interaction*) × 2 (*Centre-of-mass Interaction*) × 2 (*Set*) × 3 (*Type*) × 5 (*Position*) × 2 (*Distance*) × 4 (*Preposition*) was conducted (*Precision Interaction*, *Centre-of-mass Interaction*, *Set*, *Type*, *Position* and *Distance* within, *Preposition* between). Only the ratings of the primary prepositions of each group was included in the model; the *nedanför* ratings were excluded from group 1, the *under* ratings from group 2, the *ovanför* ratings from group 3 and the *över* ratings from group 4. Secondary control ratings were also excluded. The levels of the *Set* factor are each of the two image sets of each experimental image group (see section 3.1.4.) The levels of the *Type* factor are *Prototypical*, *Aprototypical* and *Primary Control*. The result of this ANOVA is displayed in table 5. Results for the *Set* factor and redundant interactions are excluded.

Table 5. Results of a mixed ANOVA for ratings of the primary prepositions of each group with secondary control ratings excluded.

	Source	***df*1**	***df*2**	***MS***	***F***	***p***
Within groups	Precision	1	68	194.01	35.86	.001***
	Centre-of-mass	1	68	25.75	5.18	.026*
	Type	2	136	169.4	25.68	.001***
	Position	4	272	4451.86	178.81	.001***
	Distance	1	68	23.63	6.54	.013*
	Precision × Centre-of-mass	1	68	62.23	15.06	.001***
	Precision × Type	2	136	5.44	6.61	.002**
	Precision × Position	4	272	82.16	46.85	.001***
	Precision × Distance	1	68	17.32	26.27	.001***
	Centre-of-mass × Type	2	136	48.95	26.19	.001***
	Centre-of-mass × Position	4	272	278.67	50.73	.001***
	Centre-of-mass × Distance	1	68	0.06	0.08	.777 *ns*
	Type × Position	8	544	35.51	21.78	.001***
	Type × Distance	2	136	1.69	1.72	.183 *ns*
	Position × Distance	4	272	17.48	17.49	.001***
	Precision × Centre-of-mass × Position	4	272	68.02	42.29	.001***
Between groups	Preposition	3	68	1483.55	5.6	.002**
	Precision × Preposition	3	68	9.66	1.79	.158 *ns*
	Centre-of-mass × Preposition	3	68	23.39	4.7	.005**
	Type × Preposition	6	68	30.13	4.57	.001***
	Position × Preposition	12	68	27.85	1.12	.345 *ns*
	Distance × Preposition	3	68	9.09	2.52	.065 *ns*

Note: *ns* = non-significance, $p > .05$; * $p < .05$; ** $p < .01$; *** $p < .001$

4.2.1. ***Dynamics*: the effect of functional fulfilment**

Since *Dynamics* is correlated with other variables and since image sets of the same interaction types have different dynamic positions, *Dynamics* could not function as a separate factor within an ANOVA model. To determine the influence of functional fulfilment on ratings, two 3 (*Type*) × 2 (*Preposition*) ANOVAs (*Type* within, *Preposition* between) were conducted across dynamic ratings only, the first for the *över* and *ovanför* groups and the second for the *under* and *nedanför* groups. Both ANOVAs show a significant main effect of *Type* [Group 1 & 2: $F_{2, 2228} = 179.89$, $p < .001$; Group 3 & 4: $F_{2, 2012} = 74.35$, $p < .001$] with contrasts between prototypical and control ratings [Group 1 & 2: $F_{1, 1114} = 234.61$, $p < .001$; Group 3 & 4: $F_{1, 1006} = 103.57$, $p < .001$] and between aprototypical and control ratings [Group 1 & 2: $F_{1, 1114} = 215.26$, $p < .001$; Group 3 & 4: $F_{1, 1006} = 88.26$, $p < .001$]. These results, displayed in figure 11, show that both prototypical and aprototypical ratings are significantly higher than control ratings. The ANOVAs also reveal significant interactions between *Type* and *Preposition* [Group 1 & 2: $F_{2, 2228} = 13.2$, $p < .001$; Group 3 & 4: $F_{2, 2012} = 3.49$, $p < .05$], further discussed in 4.3.

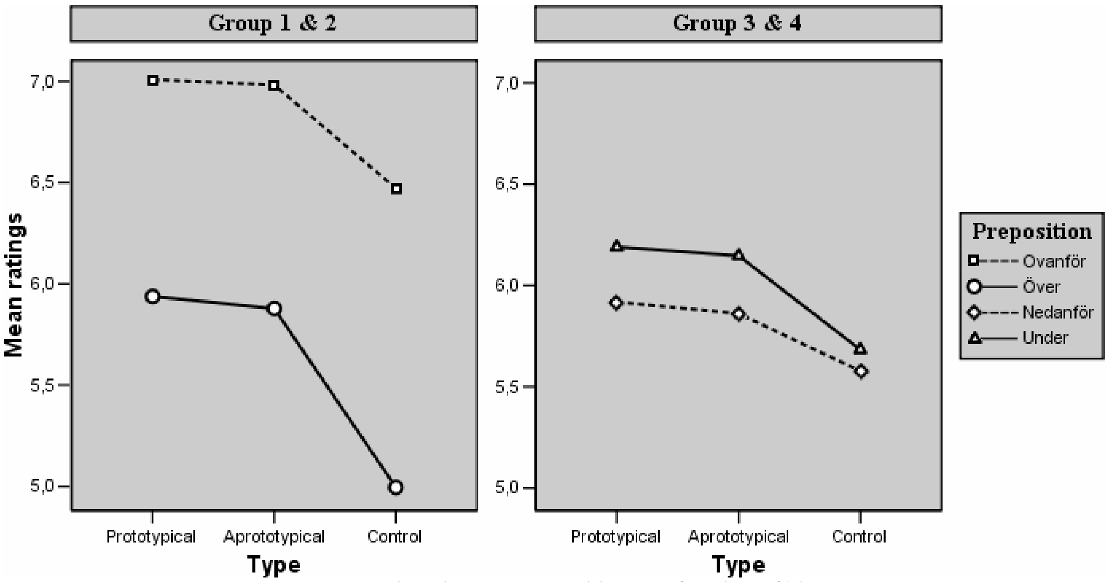


Figure 11. Dynamic ratings per preposition as a function of *Type*.

4.2.2. ***Precision* and *Centre-of-mass Interaction*: interaction types**

This section is concerned with the interplay between the interaction variables and thus the differences between interaction types. Basically, the section covers how the influence of the functional interaction differs depending on the shape and the parts of the spatially related objects.

As seen in table 5, there is a main effect of both *Precision* and *Centre-of-mass Interaction*. There are also interactions between each of these variables and *Position,* as well as an interaction between both of the variables together and *Position*. This shows that the interaction variables have a significant impact on ratings, and more specifically that these variables influence ratings of different positions in systematic ways. There are also significant interactions between these variables and *Type*, showing that they influence ratings of prototypical, aprototypical and control images differently. These influences are illustrated in figure 12, and further discussed below.

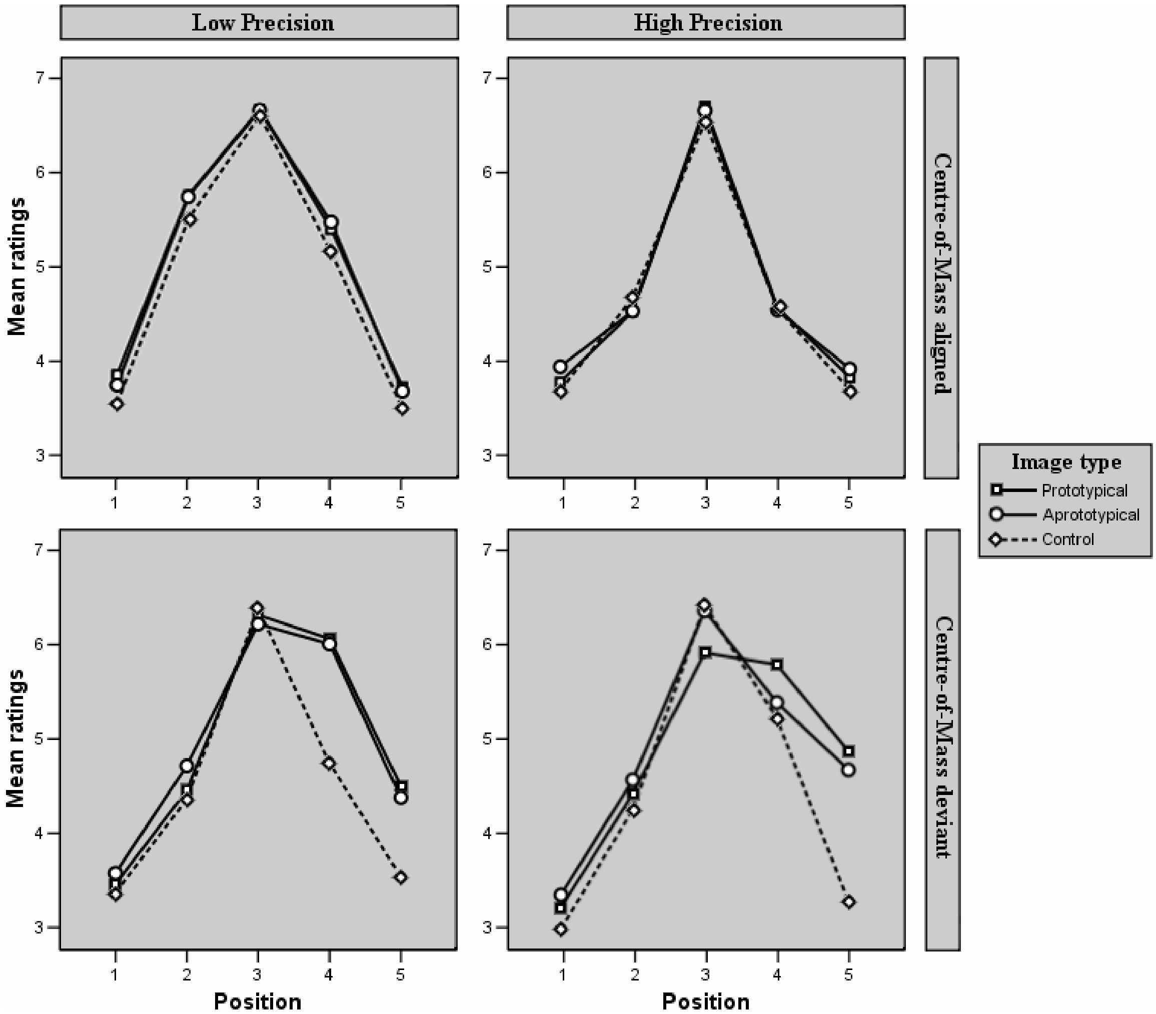


Figure 12. Mean ratings of the prepositions associated with each group as a function of *Type* and the interaction variables.

Low precision ratings differ from high precision ratings in the following ways. Experimental ratings of low precision images (M = 5.08, SD = 1.96) are higher than experimental ratings of high precision images (M = 4.85, SD = 1.96). This is significant between groups [Two Samples t-test, 1-tailed: $t_{11519} = 9.11$, $p < .001$] as well as within groups [Paired Samples t-tests, 1-tailed: Group 1: $t_{2879} = 6.76$, $p < .001$; Group 2: $t_{2879} = 6.33$, $p < .001$; Group 3: $t_{2879} = 8.31$, $p < .001$; Group 4: $t_{2879} = 10.09$, $p < .001$].

For control ratings, the difference between ratings of low precision images (M = 4.67, SD = 2.15) and high precision images (M = 4.53, SD = 2.17) is not significant between groups [Two Samples t-test, 2-tailed: $t_{2879} = 0.07$, $p = .942$], nor within group 1 [Paired Samples t-test, 2-tailed: $t_{719} = 0.76$, $p = .448$], but within groups 2 to 4 [Paired Samples t-tests, 2-tailed: Group 2: $t_{719} = 2.18$, $p < .05$; Group 3: $t_{719} = 3.7$, $p < .001$; Group 4: $t_{719} = 3.45$, $p < .01$].

Centre-of-mass aligned ratings differ from centre-of-mass deviant ratings in the following ways. In general, experimental ratings of centre-of-mass deviant images are higher at the side at which the threatening function is fulfilled. Ratings of the positions at that side (positions 3 to 5) (M = 5.46, SD = 1.83) are higher than ratings of the positions at the opposite side (positions 1 to 3) (M = 4.89, SD = 1.2). This is significant between [Two Samples t-test, 1-tailed: $t_{6911} = 17.61$, $p < .001$] and within groups [Paired Samples t-tests, 1-tailed: Group 1: $t_{1727} = 12.73$, $p < .001$; Group 2: $t_{1727} = 11.52$, $p < .001$; Group 3: $t_{1727} = 3.51$, $p < .001$; Group 4: $t_{1727} = 6.4$, $p < .001$]. This difference between sides is present for low precision images taken separately as well; ratings of positions 3 to 5 (M = 5.66, SD = 1.73) are higher than ratings of positions 1–3 (M = 4.81, SD = 2.01), between groups [Two Samples *t*-test, 1-tailed: t_{3455} = 19.03, p < .001] as well as within [Paired Samples *t*-tests, 1-tailed: Group 1: t_{863} = 8.63, p < .001; Group 2: t_{863} = 7.74, p < .001; Group 3: t_{863} = 7.32, p < .001; Group 4: t_{863} = 11.81, p < .001]. Experimental ratings of centre-of-mass aligned images, on the other hand, hardly differ between sides. Rather, ratings of positions 3 to 5 (*M* = 5.23, *SD* = 1,96) are somewhat *lower* than ratings of positions 1 to 3 (*M* = 5.4, *SD* = 1.96), being significant between groups [Two Samples *t*-test, 1-tailed: t_{6911} = 2.27, p < .05] but not within [Paired Samples *t*-tests, 1-tailed: Group 1: t_{1727} = 1.66, p = .097; Group 2: t_{1727} = 1.16, p = .253; Group 3: t_{1727} = 1.41, p = .16; Group 4: t_{1727} = 1.27, p = .195].

Interestingly, the control ratings of centre-of-mass deviant images are also somewhat higher at the side at which the function is fulfilled. Between groups, ratings of the positions at that side (positions 3 to 5) (*M* = 5.43, *SD* = 2.09) are significantly higher than ratings of the positions at the opposite side (positions 1 to 3) (*M* = 4.75, *SD* = 2.27) [Two Samples *t*-test, 1-tailed: t_{1727} = 4.13, p < .001]. However, within group tests revealed that this effect is only present for the *nedanför/under* set (positions 3–5: *M* = 5.31, *SD* = 2.02; positions 1–3: *M* = 4.76, *SD* = 2.18) and not for the *ovanför/över* set (positions 3–5: *M* = 4.54, *SD* = 2.3; positions 1–3: *M* = 4.5, *SD* = 2.3) [Paired Samples *t*-tests, 1-tailed: Group 1: t_{431} = 0.93, p = .35; Group 2: t_{431} = 0.83, p = .407; Group 3: t_{431} = 3.03, p < .01; Group 4: t_{431} = 4.25, p < .001]. For the control ratings of centre-of-mass aligned images, ratings of positions 3 to 5 (*M* = 5, *SD* = 2.11) do not differ from ratings of positions 1 to 3 (*M* = 5.09, *SD* = 2.09) [Two Samples *t*-test, 2-tailed: t_{1727} = 1.2, p = .231]. Within groups, ratings of positions 3 to 5 and 1 to 3 do not differ either [Paired Samples *t*-tests, 2-tailed: Group 1: t_{431} = 0.74, p = .462; Group 2: t_{431} = 0,15, p = .881; Group 3: t_{431} = 1.01, p = .317; Group 4: t_{431} = 1.83, p = .069].

Centre-of-mass aligned/low precision ratings differ from centre-of-mass aligned/high precision ratings in the following ways. As seen in figure 12, centre-of-mass aligned ratings are fairly uninfluenced by *Type*. For centre-of-mass aligned images only, two 2 (*Set*) × 3 (*Type*) × 5 (*Position*) × 2 (*Distance*) × 4 (*Preposition*) ANOVAs (*Set*, *Type*, *Position* and *Distance* within, *Preposition* between) for ratings of low and high precision images respectively were conducted. For high precision images, there is no main effect of *Type* [$F_{2, 136}$ = 1.71, p = .185] but an interaction between *Type* and *Position* [$F_{8, 544}$ = 3.52, p < .05]. For low precision images, there is a main effect of *Type* [$F_{2, 136}$ = 13.28, p < .001] with a significant contrast between experimental and control ratings only [Prototypical vs. Control: $F_{1, 68}$ = 15.19, p < .001; Aprototypical vs. Control: $F_{1, 68}$ = 14.87, p < .001; Prototypical vs. Aprototypical: $F_{1, 68}$ = 0.52, p = .473] but no interaction between *Type* and *Position* [$F_{8, 544}$ = 1.42, p = .187]. In other words, overall ratings do not differ significantly between types for high precision images; however, differences in ratings between positions vary between types. Conversely, experimental ratings of low precision images are rated significantly different from control ratings of low precision images but the differences in ratings between positions are the same across all three types. Across groups, dynamic ratings of centre-of-mass aligned images are significantly higher for experimental ratings (*M* = 6.12, *SD* = 1.47) than for control ratings (*M* = 5.85, *SD* = 1.71) [Two Samples *t*-test, 1-tailed: t_{2303} = 4.55, p < .001], indicating that functional factors did have an impact on centre-of-mass aligned ratings. However, since the effect of *Type* is small, the statistics throughout this section concern experimental as well as control ratings.

As figure 12 shows, ratings of high precision images differ from ratings of the corresponding low precision images in several ways for centre-of-mass aligned images. First, ratings at the centre-of-mass deviant positions for low precision images (*M* = 5.62, *SD* = 1.57) are significantly higher than their high precision equivalents (*M* = 4.63, *SD* = 1.69). This is significant between groups [Two Samples *t*-test, 1-tailed: t_{2879} = 23.52, p < .001] as well as within all groups [Paired Samples *t*-tests, 1-tailed: Group 1: t_{719} = 14.04, p

< .001; Group 2: t_{719} = 14.32, p < .001; Group 3: t_{719} = 17.99, p < .001; Group 4: t_{719} = 16.38, p < .001]. Secondly, high precision images are more sensitive to *Centre-of-mass Deviation* than low precision images. The difference between ratings at the centre-of-mass aligned position and the centre-of-mass deviant positions is higher for the high precision images (M = 2.06, SD = 1.84) than for their corresponding low precision images (M = 1.08, SD = 1.6), significantly between groups [Two Samples T-test, 1-tailed: t_{2879} = 22.03, p < .001] as well as within [Paired Samples t-tests, 1-tailed: Group 1: t_{719} = 13.44, p < .001; Group 2: t_{719} = 12.27, p < .001; Group 3: t_{719} = 17.69, p < .001; Group 4: t_{719} = 13.43, p < .001]. Thirdly, ratings of the proximal deviant positions are significantly lower for low precision images (M = 3.75, SD = 1.91) than for their high precision equivalents (M = 3.91, SD = 1.93). This is significant between groups [Two Samples t-test, 1-tailed: t_{2879} = 3.33, p < .001] as well as within [Paired Samples t-tests, 1-tailed: Group 1: t_{719} = 2.57, p < .05; Group 2: t_{719} = 3.97, p < .001; Group 3: t_{719} = 4.15, p < .001; Group 4: t_{719} = 2.2, p < .05]. Fourthly, high precision images are less sensitive to *Proximal Deviation* than low precision images. The difference between ratings of the centre-of-mass deviant positions and the proximal deviant positions is lower for high precision images (M = 0.72, SD = 1.44) than for the corresponding low precision images (M = 1.87, SD = 1.84). Once again, this is significant between groups [Two Samples t-test, 1-tailed: t_{2879} = 27.14, p < .001] as well as within [Paired Samples t-tests, 1-tailed: Group 1: t_{719} = 12.15, p < .001; Group 2: t_{719} = 13.65; p < .001; Group 3: t_{719} = 16.87, p < .001; Group 4: t_{719} = 16.2, p < .001].

Centre-of-mass deviant/low precision ratings differ from centre-of-mass deviant/ high precision ratings in the following ways. For centre-of-mass deviant images, *Type* seems to have a stronger influence than for centre-of-mass aligned images. Two 2 (*Set*) × 3 (*Type*) × 5 (*Position*) × 2 (*Distance*) × 4 (*Preposition*) ANOVAs (*Set*, *Type*, *Position* and *Distance* within, *Preposition* between) were conducted on centre-of-mass deviant/low precision ratings and centre-of-mass deviant/high precision ratings, respectively. For low precision ratings, there is a main effect of *Type* [$F_{2, 138}$ = 35.07, p < .001] with a significant contrast between experimental and control ratings only [Prototypical vs. Control: $F_{1, 68}$ = 35.97, p < .001; Aprototypical vs. Control: $F_{1, 68}$ = 36.72, p < .001; Prototypical vs. Aprototypical: $F_{1, 68}$ = 0.67, p = .416] and an interaction between *Type* and *Position* [$F_{8, 552}$ = 25.27, p < .001]. A main effect of *Type* [$F_{2, 138}$ = 23.28, p < .001] also with a contrast between experimental and control ratings only [Prototypical vs. Control: $F_{1, 68}$ = 19.3, p < .001: Aprototypical vs. Control: $F_{1, 68}$ = 37.26, p < .001: Prototypical vs. Aprototypical: $F_{1, 68}$ = 0.43, p = .512] and an interaction between *Type* and *Position* [$F_{8, 552}$ = 27.03, p < .001] is present for high precision images as well. These main effects reveal that experimental ratings of centre-of-mass deviant images generally differ significantly from control ratings, however there is no significant difference between prototypical and aprototypical ratings of these images. The interactions show that centre-of-mass deviant images are differently rated depending on the image type, for both high and low precision ratings.

For centre-of-mass deviant images, low precision ratings differ from high precision ratings in the following two ways. First, for experimental ratings, position 5 is rated significantly higher for high precision images (M = 4.91, SD = 1.9) than for low precision images (M = 4.54, SD = 1.92). This is significant between groups [Two Samples t-test, 1-tailed: t_{1151} = 4.81, p < .001] and within [Paired Samples t-tests, 1-tailed: Group 1: t_{287} = 4.99, p < .001; Group 2: t_{287} = 3.42, p < .001; Group 3: t_{287} = 3.96, p < .001; Group 4: t_{287} = 4.35, p < .001]. For control ratings, ratings of position 5 for high precision images (M = 3.28, SD = 2.01) are lower than ratings of position 5 for low precision images (M = 3.53, SD = 2.07). However, this is non-significant between groups [Two Samples t-test, 1-tailed: t_{287} = 1.83, p = .0681], within groups 1 and 2 [Paired Samples t-tests, 1-tailed: Group 1: t_{87} = 1.21, p = .231; Group 2: t_{87} = 1.57, p = .121], but significant within groups 3 and 4 [Paired Samples t-tests, 1-tailed: Group 3: t_{87} = 2.14, p < .05; Group 2: t_{87} = 3.04,

$p < .01$]. Secondly, positions 3 and 4 are rated higher for low precision images ($M = 6.22$, $SD = 1.32$) than for high precision images ($M = 5.9$, $SD = 1.51$), significantly between groups [Two Samples *t*-test, 1-tailed: $t_{2303} = 7.66$, $p < .001$] as well as within [Paired Samples *t*-tests, 1-tailed: Group 1: $t_{575} = 5.67$, $p < .001$; Group 2: $t_{575} = 3.63$, $p < .001$; Group 3: $t_{575} = 5.16$, $p < .001$; Group 4: $t_{575} = 6.52$, $p < .001$]. For control ratings, positions 3 and 4 are rated significantly lower for low precision images ($M = 5.56$, $SD = 1.89$) than for high precision images ($M = 5.81$, $SD = 1.81$) between groups [Two Samples *t*-test, 1-tailed: $t_{575} = 2.54$, $p < .05$], within groups 1, 3 and 4 [Paired Samples *t*-tests, 1-tailed: Group 1: $t_{143} = 3.35$, $p < .01$; Group 3: $t_{143} = 3.39$, $p < .001$; Group 4: $t_{143} = 2.18$, $p < .05$] but not group 2 [Paired Samples *t*-test, 1-tailed: $t_{143} = 1.1$, $p = .272$].

4.2.3. *Prototypicality*: the influence of functional relatedness

The ANOVA displayed in table 5 reveals no significant contrast between prototypical and aprototypical ratings [$F_{1, 68} = 1.29$, $p = .261$]. A 2 (*Precision Interaction*) × 2 (*Centre-of-mass Interaction*) × 2 (*Set*) × 2 (*Type*) × 5 (*Position*) × 2 (*Distance*) × 4 (*Preposition*) ANOVA conducted across all experimental ratings (*Precision Interaction*, *Centre-of-mass Interaction*, *Set*, *Type*, *Position* and *Distance* within, *Preposition* between) was also conducted. This ANOVA reveals no main effect of *Type* [$F_{1, 68} = 0.01$, $p = .919$] but a significant interaction between *Type* and *Position* [$F_{4, 272} = 12.2$, $p < .001$] and *Type* and *Distance* [$F_{1, 68} = 5.86$, $p < .01$], displayed in figure 13. The interaction between *Type* and *Position* shows that prototypical ratings are affected by *Position* somewhat differently than aprototypical ratings. These differences in ratings can be seen in figure 12.

In general, dynamic positions are rated somewhat higher for prototypical images ($M = 5.96$, $SD = 1.58$) than for aprototypical images ($M = 5.90$, $SD = 1.58$). This effect is small but significant between groups [Two Samples *t*-test, 1-tailed: $t_{4257} = 3.76$, $p < .001$] and within groups 2 to 4 [Paired Samples *t*-tests, 1-tailed: Group 2: $t_{1061} = 2.02$, $p < .05$; Group 3: $t_{1061} = 2.14$, $p < .05$; Group 4: $t_{1061} = 2.37$, $p < .05$] but not within group 1 [Paired Samples *t*-test, 1-tailed: $t_{1061} = 1.88$, $p = .061$]. On the contrary, ratings of undynamic positions are somewhat higher for aprototypical images ($M = 4.41$, $SD = 1.94$) than for prototypical images ($M = 4.38$, $SD = 1.95$). Again, this effect is small but significant between groups [Two Samples *t*-test, 1-tailed: $t_{7271} = 2.34$, $p < .05$], but within group 3 only [Paired Samples *t*-tests, 1-tailed: Group 1: $t_{1817} = 0.95$, $p = .34$; Group 2: $t_{1817} = 1.38$, $p = .168$; Group 3: $t_{1817} = 2.9$, $p < .01$ Group 4: $t_{1817} = 0.86$, $p = .39$].

Further analyses showed that this difference between prototypical and aprototypical ratings is only present for centre-of-mass deviant images, which can be seen in figure 12. The relevant means and the results of the Paired Samples *t*-tests are displayed in table 6.

Table 6. Means and results of Paired Samples *t*-tests for experimental ratings.

	Group	Dynamic ratings					Undynamic ratings				
		Mean and std. dev.		*t*-tests, 1-tailed			Mean and std. dev.		*t*-tests, 1-tailed		
		Proto.	Aproto.	*t*	*df*	*p*	Proto.	Aproto.	*t*	*df*	*p*
C.o.m. Deviant	Group 1	5.99 (1.5)	5.92 (1.48)	1.93	485	.055 *ns*	5.07 (1.83)	5.09 (1.86)	1	953	.317 *ns*
	Group 2	5.11 (2)	4.95 (2.02)	2.69	485	.007**	4.1 (2.06)	4.18 (2.04)	1.1	953	.057 *ns*
	Group 3	5.51 (1.7)	5.33 (1.74)	4.1	485	.001***	4.61 (1.82)	4.74 (1.8)	3.45	953	.001***
	Group 4	6.08 (1.52)	5.92 (1.6)	3.19	485	.002**	4.64 (2.1)	4.65 (2.12)	0.88	953	.381 *ns*
	Total	5.67 (1.73)	5.53 (1.77)	5.55	1943	.001***	4.6 (1.99)	4.67 (1.98)	2.96	3815	.003**
C.o.m. Aligned	Group 1	6.44 (1.15)	6.42 (1.08)	1.11	575	.268 *ns*	4.77 (1.73)	4.77 (1.71)	0.73	863	.467 *ns*
	Group 2	5.75 (1.76)	5.75 (1.7)	0.7	575	.487 *ns*	3.36 (1.79)	3.34 (1.77)	0.9	863	.367 *ns*
	Group 3	6.27 (1.24)	6.32 (1.12)	1.66	575	.098 *ns*	4.21 (1.71)	4.22 (1.69)	0.78	863	.436 *ns*
	Group 4	6.37 (1.27)	6.37 (1.22)	0.73	575	.467 *ns*	4.2 (1.98)	4.2 (1.93)	0.71	863	.477 *ns*
	Total	6.2 (1.4)	6.22 (1.33)	0.36	2303	.917 *ns*	4.14 (1.87)	4.13 (1.85)	0.72	3455	.473 *ns*

Note: *ns* = non-significance, $p > .05$; * $p < .05$; ** $p < .01$; *** $p < .001$

Concerning centre-of-mass aligned images, ratings of dynamic positions are not significantly higher for prototypical images than for aprototypical images. Nor are ratings of undynamic positions significantly higher for aprototypical images than for prototypical ones.

For centre-of-mass deviant images, ratings of dynamic positions are significantly higher for prototypical images than for aprototypical ones, whereas ratings of undynamic positions are significantly higher for aprototypical images than for prototypical ones. These differences are significant at least between groups.

Prototypical and aprototypical ratings are also differentially influenced by *Distance*, as shown by the interaction between *Type* and *Distance*. As seen in figure 13, prototypical ratings are less sensitive to differences in distance than aprototypical ratings. The difference in ratings between images with a *Near* distance and images with a *Far* distance is bigger for aprototypical ratings than for prototypical ones. The influence of *Distance* is thus somewhat stronger on ratings of aprototypical images than on ratings of prototypical images. This effect is small but significant.

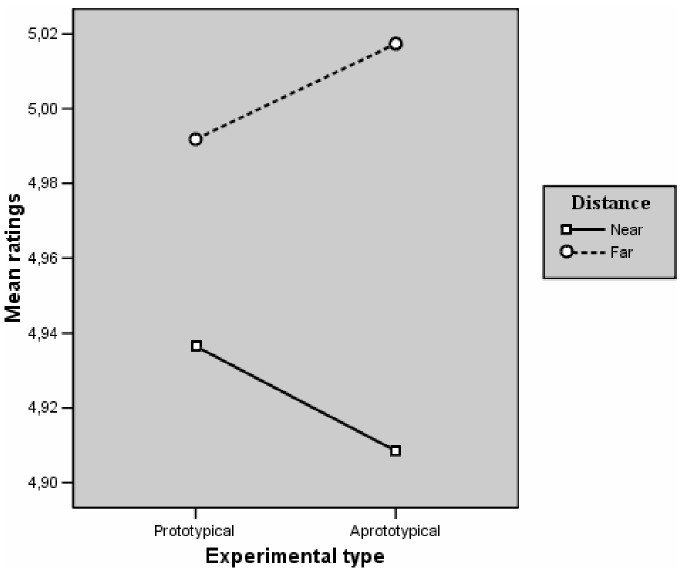


Figure 13. Interaction between *Type* and *Distance* for experimental ratings.

4.3. INFLUENCES OF THE FUNCTIONAL PART OF THE LOCATED OBJECT

Another aim of the experiment is to assess the joint influence of the position of the centre-of-mass of the located object and the position of the centre of the functional part of the located object on ratings. Therefore, the experiment included secondary control images corresponding only to centre-of-mass deviant images. Within groups 3 and 4, the secondary control images corresponded only to centre-of-mass deviant/high precision images. These secondary control images contained a control object positioned at the centre of the functional part of the located object, instead of at its centre-of-mass. Primary and secondary control ratings were collapsed, yielding a control estimate which is regarded as an estimate of the shared influence of the position of the centre-of-mass of the located object and the position of its functional part on ratings.

Two ANOVAs were conducted for centre-of-mass deviant ratings, one 2 (*Set*) × 3 (*Type*) × 5 (*Position*) × 2 (*Distance*) × 2 (*Preposition*) for low precision ratings, and one 2 (*Set*) × 3 (*Type*) × 5 (*Position*) × 2 (*Distance*) × 4 (*Preposition*) (*Set*, *Type*, *Position* and *Distance* within, *Preposition* between) for high precision ratings. In both ANOVAs, the levels of the *Type* factor are *Prototypical*, *Aprototypical* and *Control Estimate*. The results were striking. There are main effects of *Type* [Low Precision ratings: $F_{2, 68} = 46.09$, $p < .001$; High Precision ratings: $F_{2, 68} = 47.68$, $p < .001$]. Importantly, there is no interaction between *Type* and *Position* for low precision ratings [$F_{8, 272} = 1.75$, $p = .088$], as displayed in figure 14. For high precision ratings, an interaction between *Type* and *Position* is present [$F_{8, 272} = 15.94$, $p < .001$]. However, there is no significant contrast between prototypical ratings and control estimates within this interaction [$F_{1, 119} = 2.62$, $p = .109$]. In other words, although both prototypical and aprototypical ratings are significantly higher than control estimates, the pattern of the control estimates of both low and high precision images matches the pattern of prototypical ratings, as can be seen in figure 14. For low precision images, the pattern of the control estimates matches the patterns of both prototypical and aprototypical ratings, i.e., the pattern of experimental ratings overall.

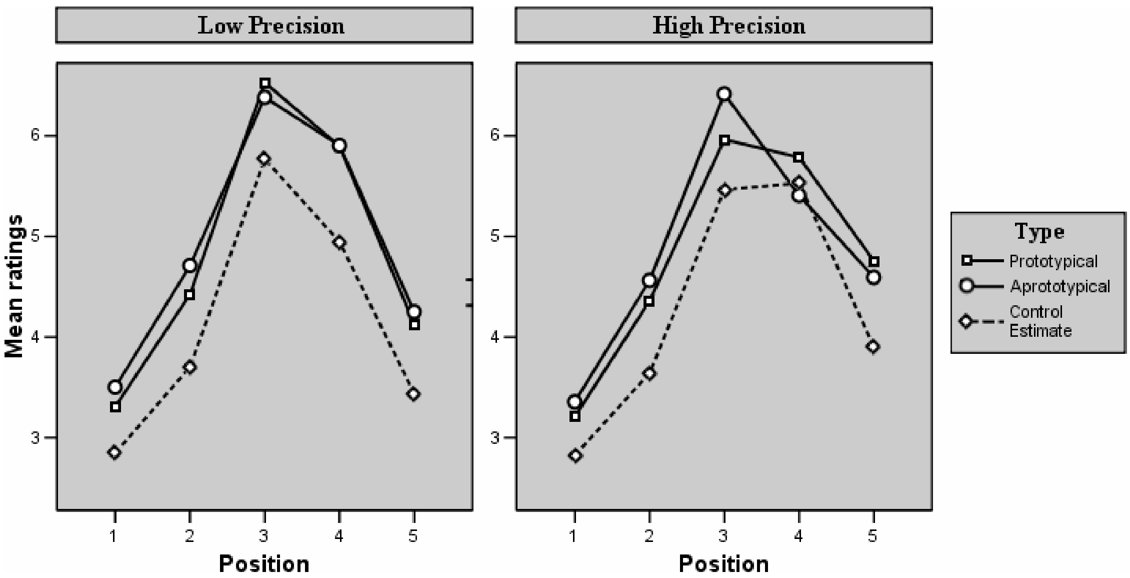


Figure 14. Mean of centre-of-mass deviant ratings as a function of experimental ratings and control estimates.

4.4. DIFFERENCES BETWEEN PREPOSITIONS

For control images, ratings do not significantly differ between prepositions as seen in table 3. There is no main effect of *Preposition* nor any significant interactions between *Preposition* and any other factors. However, with the experimental ratings included in the analysis, ratings do vary significantly between prepositions. As seen in table 5, there is a main effect of *Preposition* as well as a significant interaction between *Type* and *Preposition* as well as between *Centre-of-mass Interaction* and *Preposition*. The main effect of *Preposition* shows that ratings vary significantly between prepositions. However, a post-hoc test (Tukey HSD) revealed that differences in ratings between prepositions are only significant between *ovanför* and *över* ($D = 1.41$; $p < .01$) but not between *nedanför* och *under* ($D = 0.01$; $p = 1.00$). Ratings of *ovanför* ($M = 5.41$, $SD = 1.75$) are significantly higher than ratings of *över* ($M = 4$, $SD = 2.15$) whereas ratings of *nedanför* ($M = 4.89$, $SD = 1.88$) do not differ from ratings of *under* ($M = 4.89$, $SD = 2.13$).

The interaction between *Preposition* and *Type*, displayed in figure 15, turned out to be significant only for *ovanför* and *över*. Two 2 (*Precision Interaction*) × 2 (*Centre-of-mass Interaction*) × 2 (*Set*) × 3 (*Type*) × 5 (*Position*) × 2 (*Distance*) × 2 (*Preposition*) ANOVAs were conducted (*Precision Interaction*, *Centre-of-mass Interaction*, *Set*, *Type*, *Position* and *Distance* within, *Preposition* between), the first for the *ovanför/över* set and the second for the *nedanför/under* set. These ANOVAs show a significant interaction between *Preposition* and *Type* for *ovanför* and *över* [$F_{2, 68} = 6.34, p < .01$] but not for *nedanför* and *under* [$F_{2, 68} = 0.15, p = .862$]. As seen in figure 15, the mean difference between prototypical and aprototypical ratings on the one hand and control ratings on the other is lower for ratings of *ovanför* (Prototypical vs. Control: $M = 0.2$, $SD = 1.37$; Aprototypical vs. Control: $M = 0.23$, $SD = 1.39$) than for ratings of *över* (Prototypical vs. Control: $M = 0.66$, $SD = 1.86$; Aprototypical vs. Control: $M = 0.68$, $SD = 1.78$), both of these differences being significantly lower for *ovanför* than for *över* [Two samples *t*-tests, 1-tailed: Prototypical vs. Control: $t_{1439} = 7.72$, $p < .001$; Aprototypical vs. Control: $t_{1439} = 7.73$, $p < .001$]. This shows that ratings of *över* are influenced by functional factors to a greater extent than ratings of *ovanför*. These differences are somewhat lower for ratings of *nedanför* (Prototypical vs. Control: $M = 0.12$, $SD = 1.43$; Aprototypical vs. Control: $M = 0.15$, $SD = 1.36$) than for ratings of *under* (Prototypical vs. Control: $M = 0.18$, $SD = 1.5$; Aprototypical vs. Control: $M = 0.17$, $SD = 1.42$), but not significantly [Two samples *t*-tests, 1-tailed: Prototypical vs. Control: $t_{1439} = 1,562$; $p = 0.119$, Aprototypical vs. Control: $t_{1439} = 0.94$, $p = .349$]. This indicates that *under* and *nedanför* are not differentially influenced by functional factors. However, as mentioned in 4.2.1, analyses of dynamic ratings only did reveal a significant interaction between *Preposition* and *Type* for groups 3 and 4, that is, for *nedanför* and *under*.

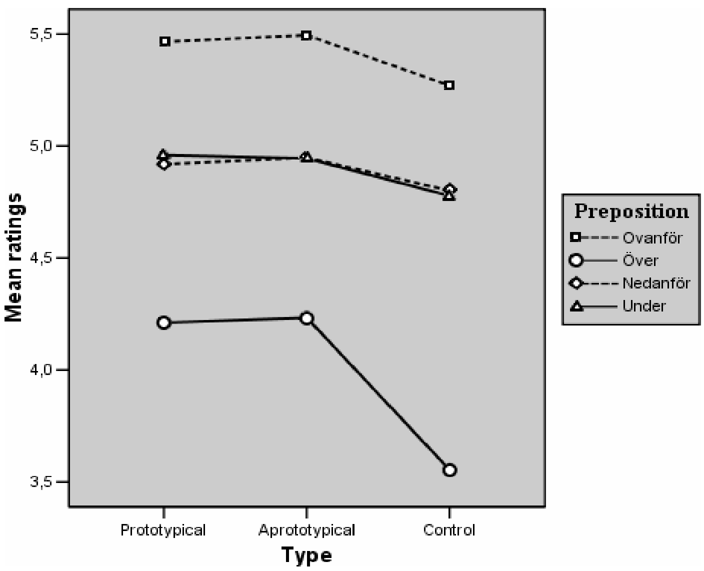


Figure 15. Mean ratings per preposition as a function of *Type*.

5. Discussion

5.1. INFLUENCES ON THE COMPREHENSION OF SWEDISH PROJECTIVES

5.1.1. Geometric influences

As discussed in section 3.1.1. and 3.1.3., a general prediction is that the appropriateness of Swedish vertical projective prepositions are influenced by geometric factors as predicted by the AVS-model. As shown by the results in section 4.1., this is in fact the case.

According to the AVS-model, the shape of the reference object should influence acceptability ratings, as the locations at which the vectors are rooted depend on it, which in turn affects the orientation of the vector sum (see section 2.3.5.). As shown in section 4.1.1., there was a main effect of *Shape*, showing that the shape of the reference objects did have a significant impact on ratings of the control images. Furthermore, there were significant interactions between *Shape* and *Position* on the one hand, and *Shape* and *Distance* on the other. This is to be expected if the shape of the reference object influences the orientation of the vector sum. As the vector sum orientation projected towards a specific position will vary across different reference objects, acceptability ratings are expected to vary as well. That is, ratings of a specific position at a specific distance will be influenced by the shape of the reference object, and hence, interactions between these factors are to be expected.

The AVS-model predicts that acceptability ratings depend on the deviation between the centre-of-mass orientation and upright vertical as well as the deviation between the proximal orientation and upright vertical (see section 2.3.5.). Accordingly, ratings will drop as a function of *Centre-of-mass Deviation*, and *Proximal Deviation* will further reduce ratings. As shown in section 4.1.2., *Position* had a significant impact on ratings as they dropped as a function of *Centre-of-mass* and *Proximal Deviation*. Also, the proportional drop in ratings from the centre-of-mass deviant positions to the proximal deviant positions was significantly higher than the drop from the centre-of-mass aligned position to the centre-of-mass deviant positions. This shows that the *Proximal Deviation* further reduces the drop in ratings caused by the *Centre-of-mass Deviation*.

As the distance between the objects affects the size of the attentional beam, which in turn affects the vector summation, a close distance causes the orientation of the vector sum to approach proximal orientation, whereas a far distance makes the vector sum orientation approach centre-of-mass orientation (see section 2.3.5.). *Proximal Deviation* should therefore have a higher influence on ratings than *Centre-of-mass Deviation* when the objects are close, whereas *Centre-of-mass Deviation* should have a higher impact on ratings than *Proximal Deviation* when they are further apart. Across all groups, there was a main effect of *Distance* and, importantly, a significant interaction between *Distance* and *Position*. This interaction, illustrated in figure 10, showed that *Proximal Deviation* had a higher influence on ratings at a *Near* distance than at a *Far* distance (see section 4.1.3.). However, within-group analyses yielded inconclusive results; the enhanced effect of *Proximal Deviation* at the *Near* distance being significant only for the *ovanför* and *nedanför* groups.

Overall, the results show that acceptability judgments about the Swedish vertical projectives *över*, *ovanför*, *under* and *nedanför* all are influenced by geometric factors as predicted by the AVS-model. These factors are the shape of the reference object, the centre-of-mass and proximal deviation and the distance between the objects, although this last influence was small.

5.1.2. Functional influences

The main purpose of the present study is to examine if the comprehension of Swedish projectives is influenced by functional factors in the same ways as their English counterparts (see section 3.1.1.). Functional influences are evaluated by comparing the regions of acceptability of the experimental images with the regions of acceptability of the control images. As the geometric manipulations are held constant across these images, any significant differences in ratings have to be attributed to functional factors.

As discussed in section 2.4.1., a number of studies have shown that the comprehension of English projectives is influenced by the force-dynamic interaction between the spatially related objects, and more specifically, whether or not one of the objects is fulfilling a threatening or protecting function. In the present study, the influence of the force-dynamic interaction between the objects was examined by manipulating whether one of the objects was fulfilling a threatening function (see section 3.1.3.). Judgments about whether a threatening function is fulfilled depend on knowledge about what functions the objects afford, and such knowledge is closely tied to the shape and the parts of those objects (see sections 2.4.2. and 2.4.5.). Whether or not the threatening function was fulfilled in the images depended on whether the functional part of the located object was aligned with the functional part of the reference object in a manner that afforded their interaction. Thus the located object had to be positioned at specific dynamic positions in order for the function to be fulfilled. As discussed in section 3.1.3., the prediction is that experimental ratings of the dynamic positions are significantly higher than their corresponding control ratings. Also, as the threatening function is only fulfilled at positions at one side of centre-of-mass deviant images, experimental ratings of centre-of-mass deviant images are predicted to be significantly higher at the side at which the function is fulfilled.

To further explore the importance of the shape and the parts of the objects, the position of the functional part of the reference object and the precision required to fulfil the function were manipulated. As these factors determine at which positions the threatening function is fulfilled, they are predicted to influence the regions of acceptability in systematic ways, as outlined in section 3.1.3.

The relevant results of the experiment presented in section 4.2. confirm these predictions. As seen in section 4.2.1., experimental ratings of dynamic positions were significantly higher than the corresponding control ratings (see figure 11). Also, as seen in section 4.2.2., experimental ratings of centre-of-mass deviant images were significantly higher at the side at which the function is fulfilled. Importantly, this contrasts with experimental ratings of centre-of-mass aligned images, in which the dynamic positions of each side correspond to each other. Across groups, these ratings are somewhat *lower* at the side in which the function is fulfilled in the centre-of-mass deviant images, and, within groups ratings do not significantly differ between sides (see figure 12). These results confirm that the appropriateness of Swedish vertical projectives are influenced by the inferred force-dynamic interaction between the spatially related objects, and more specifically, by whether or not one of the objects is fulfilling a threatening function, as has been shown for the corresponding English prepositions. In addition, as judgments about whether or not the threatening function is fulfilled presuppose knowledge about the functional parts of the related objects, these results show that knowledge about the functions of the related objects also influences the appropriateness of Swedish vertical projectives.

Furthermore, as shown in section 4.2.2., the position of the functional part of the reference object and the precision required to fulfil the function influenced ratings of different positions in systematic ways. That is, there were main effects of both of the interaction variables, and both of them interacted with *Position*. Importantly, experimental and control ratings were differentially influenced by these factors, apparent from the interaction between the interaction variables and *Type* on the one hand, and *Position* and *Type* on the other. The fact that control ratings are influenced in accordance with the predictions of the AVS-model indicates that functional influences interfere with geometric influences in systematic ways. That is, the regions of acceptability of the control images are in accordance with the AVS-model, whereas the regions of the experimental images are influenced by functional factors in systematic ways that cannot be accounted for by the AVS-model. This is illustrated in figure 12.

Overall, the regions of acceptability of the experimental ratings, presented in section 4.2.2., depend on the positions at which the threatening function can be fulfilled and they are at large influenced as predicted in section 3.1.3. First, experimental ratings are significantly higher for low precision images than for high precision images, as the threatening function can be fulfilled at a number of positions in the former but only at one in the latter. Secondly, as discussed above, experimental ratings are significantly higher at the side at which the function is fulfilled for centre-of-mass deviant images, whereas ratings do not significantly differ within groups for the corresponding centre-of-mass aligned images. This is to be expected as the threatening function is fulfilled in the same positions at each side in the latter images. Thirdly, for centre-of-mass aligned images, the ratings of the centre-of-mass deviant positions are higher for low precision images than for high precision images, which shows that high precision images are more sensitive to *Centre-of-mass Deviation* than low precision images. Also, ratings of the proximal deviant positions are significantly lower for low precision images than their high precision equivalents. That is,, high precision images are less sensitive to *Proximal Deviation* than low precision images. Although ratings of the proximal deviant positions were predicted not to differ between high precision and low precision images, these results confirm the general prediction that, for centre-of-mass aligned images, the centre-of-mass deviant positions are rated significantly higher for low precision images than for high precision images as the threatening function is fulfilled at these positions for the former but not for the latter. Finally, for centre-of-mass deviant images, experimental ratings of position 5 are significantly higher for high precision images than for low precision images and, in contrast, experimental ratings of positions 3 and 4 are significantly higher for low precision images than for high precision images, as predicted. These results are to be expected as the threatening function is only fulfilled at position 5 in the high precision images, whereas it is fulfilled at positions 3 to 5 in the low precision images.

These results show that aspects of the shape and the parts of the spatially related objects, as the position of the functional part of the reference object and the precision required to fulfil the interaction, are important determinants of functional interactions, and consequently, influence judgments about the appropriateness of projectives, in that they influence the patterns of the regions of acceptability in predictable manners that cannot be accounted for by geometric factors.

In contrast to the predictions outlined section 3.1.3., some of these patterns also emerged in the regions of acceptability of the control ratings. For the *under/nedanför* set, the control ratings of centre-of-mass deviant images are significantly higher at the side at which the function is fulfilled in the corresponding experimental images, whereas there is no difference between sides in the corresponding centre-of-mass aligned images (see section 4.2.2.). However, as function is highly correlated with form (see section 2.4.5.), this might be expected. Three of the reference objects in the centre-of-mass deviant images of the *under/nedanför* set were either a tap or a water pump (see appendix 1). As the shapes of either side of these objects differ from each other, the increase in ratings of their functional side might be due to the shapes of the reference objects. The reference objects in the centre-of-mass deviant images of the *över/ovanför* set were all similar in shape at either side and control ratings of these images were no higher at the functional side. Thus the biases of the control ratings of the *under/nedanför* set appear to depend on the shape of the reference objects.

Also, experimental and control ratings of centre-of-mass aligned images hardly differed, and the patterns in ratings of these images presented in section 4.2.2. concerned both experimental and control images. This indifference in ratings might be due to the shapes of the located objects. The located objects in the low precision images where generally wider (*M* = 13.84 mm, *SD* = 7.95 mm) than the located objects in the high precision images (*M* = 5.59 mm, *SD* = 2.96 mm). Consequently, as the control object in the primary control images is positioned at the centre-of-mass of the located object in the corresponding experimental images (see sections 3.1.1. and 3.1.2.), the *Proximal Deviation* is generally higher at the proximal deviant positions and the *Centre-of-mass Deviation* is generally lower at the centre-of-mass deviant positions in the low precision images than in the high precision images. This should yield a higher drop in ratings from the centre-of-mass aligned position to the centre-of-mass deviant positions for low precision images than for high precision images, and a lower drop in ratings from the centre-of-mass deviant positions to the proximal deviant positions for low precision images than for high precision images. Thus the regions of acceptability of the control ratings of the centre-of-mass aligned images should follow the same pattern as their corresponding experimental ratings, due to the width of the located objects in these images. To test if the width of the located objects had such an influence on control ratings of centre-of-mass aligned images, these ratings were divided into two groups, based on the width of the objects. The first group contained ratings of images with the four widest located objects whereas the second contained ratings of images with the four narrowest objects. The difference in ratings from the centre-of-mass aligned position to the centre-of-mass deviant positions and the difference from the centre-of-mass deviant positions to the proximal deviant positions where compared between the two groups. This procedure confirmed that width had an impact on ratings. The first mean difference is significantly higher for the group with narrow located objects (*M* = 1.73, *SD* = 2.15) than for the group with wide objects (*M* = 1.44, *SD* = 1.74) [Two Samples *t*-test, 1-tailed: t_{575}= 2.7, $p < .01$]. The second mean difference is, on the other hand, significantly lower for the group with narrow objects (*M* = 0.94, *SD* = 1.49) than for the group with wide objects (*M* = 1.78, *SD* = 1.83) [Two Samples *t*-test, 1-tailed: t_{575}= 8.8, $p < .001$]. This implies that geometric factors concerned with the width of the located object were confounded with functional factors concerned with the precision of the interaction in centre-of-mass aligned images. This is further discussed in section 5.3. However, as dynamic ratings were significantly higher for experimental images than for control images (see section 4.2.2.), functional factors did have an impact in centre-of-mass aligned images, independently of the geometry of the located objects.

Finally, as reported in section 2.4.2., knowledge about whether or not the objects are functionally related influences the applicability of English vertical projectives. Such influence is also investigated in the present study and functional relatedness is predicted to yield an increase in ratings of positions at which the threatening function is fulfilled. As shown in section 4.2.3., although there was no main effect of *Type*, ratings of dynamic positions were somewhat influenced by functional relatedness. Specifically, analyses across all of the experimental ratings showed that *Prototypicality* was associated with an increase in ratings of dynamic positions and a decrease of undynamic positions in centre-of-mass deviant images but had no influence on ratings of centre-of-mass aligned images. The influence of the threatening function should be higher for centre-of-mass deviant images as the function is fulfilled at positions disassociated from the centre-of-mass of the reference object. Thus, if a small effect of functional relatedness is present, it is unsurprising that it only has an impact on centre-of-mass deviant images. Finally, across experimental images, prototypical images were less influenced by *Distance* than aprototypical images. This might be expected as the functional interaction is more salient in the functionally related images, and the geometric influence of distance should thus be weaker in such images. These results confirm that judgments about the appropriateness Swedish vertical projectives are influenced by knowledge about whether or not the spatially related objects are functionally related, as has been shown for the corresponding English prepositions.

5.1.3. The influence of the functional part of the located object

As outlined in the previous section, and as noticed by Carlson & Covell (2005), the functional interaction between two objects does not only depend on the affordances of the reference object, but also on the affordances of the located object and hence on its shape and parts (see section 2.4.5.) The extended version of the AVS-model, presented in section 2.5.1., can account for the functional influence of the functional part of the reference object, but does not take the shape of the located object into account and assumes that it schematizes to a point. In contrast, the results of the present work show support for the importance of the shape of the located object, and more specifically, an influence of its functional part.

As discussed in section 3.1.3., the extended version of the AVS-model can account for a functional bias in ratings towards the functional part of the reference object when that part is misaligned with the centre-of-mass of the object and its location is thus asymmetric. However, in cases where the functional part of the reference object either is aligned with its centre-of-mass, or extends completely along its upper side and is therefore symmetrically positioned, the model is unable to predict a bias. That is, the model cannot account for a functional bias towards the side at which the threatening function is fulfilled in the low precision/centre-of-mass deviant images (see figure 8), in which the location of the functional part of the reference object is symmetric. As the model accounts for the functional bias in terms of extra attention paid to the functional part of the reference object and as attention has to be equally distributed across both sides of the reference objects in these images, any asymmetric biases have to be attributed to the asymmetry of the located object, and hence to its functional part. The fact that ratings of the low precision/centre-of-mass deviant images were significantly higher at the side of the functional part (see section 4.2.2.) thus shows that the functional part of the located object had an impact on ratings. Also, as this bias was absent in the corresponding control ratings of the *över/ovanför* set, it has to be attributed to functional factors at least in this set.

To further explore the influence of the functional part of the located object, secondary control ratings corresponding to the functional part of the located object in centre-of-mass deviant images were included in the experiment. As primary control ratings correspond to the location of the centre-of-mass of the located object, and secondary control ratings to the location of its functional part, an estimate of the joint influence of both locations, the control estimate, was obtained by collapsing primary and secondary control ratings (see section 3.1.3.). If ratings of experimental images depend on attention paid to both of these locations, and not only to the location of the centre-of-mass of the object, the regions of acceptability of the experimental ratings should correspond to the estimated regions of acceptability of the control estimates. As shown in section 4.3., this was indeed the case. Although experimental ratings were significantly higher than control estimates, the pattern of the control estimates matched the pattern of experimental ratings for low precision images, and for high precision images the pattern matched the pattern of prototypical ratings. This was evident from the absence of significant interactions. Importantly, this shows that the regions of acceptability of at least prototypical ratings can be predicted from the joint influence of the position of the centre-of-mass and the position of functional part of the located object. This, in turn, suggests that prototypical ratings in large depend on the position of the centre-of-mass of the located object as well as the position of its functional part.

These results show, as suggested by Carlson & Covell (2005), that the functional part of the located object is of importance for the functional relation between the spatially related objects. In contrast to the AVS-model and the extended version of it, the shape of the located object influences the process of apprehension of projective relations and has to be accounted for when the goodness-of-fit between a projective relation and projective predicate is established (see section 2.3.5.). This is further discussed in section 5.4.

5.2. DIFFERENCES BETWEEN PREPOSITIONS

A final aim of this study is to examine if appropriate judgments about the prepositions *över* and *under* are influenced by functional factors to a greater extent than judgments about *ovanför* and *nedanför*. As discussed in section 2.4.4., a number of studies have shown that the influence of function on the applicability of English projectives is stronger for *over* and *under*, corresponding to the former Swedish projectives, than for *above* and *below*, corresponding to the latter.

5.2.1. Differences between *över* and *ovanför*

The results of the present study show that acceptability judgments about *över* and *ovanför* are differentially influenced by functional factors as predicted. As presented in section 4.4., acceptability ratings of *ovanför* were generally higher than ratings of *över*. Ratings of *Över* was also more sensitive to functional influences than ratings of *ovanför*. Specifically, the difference between experimental and control ratings was significantly higher for *över* than for *ovanför* across all groups and within groups 1 and 2, showing that functional factors, only available in experimental images, had a overall stronger influence on ratings of *över* than on ratings of *ovanför*. Across ratings of dynamic positions, the influence of functional factors was also stronger on ratings of *över* than on ratings of *ovanför* (see section 4.2.1.).

5.2.2. Differences between *under* and *nedanför*

The influence of function on ratings of *under* and *nedanför*, on the other hand, turned out to be practically the same. Across all groups as well as within groups 3 and 4, there was no general difference in ratings between the prepositions nor was the influence of function significantly stronger for either of the prepositions (see section 4.4.). The difference between experimental and control ratings was somewhat higher for *under* than for *nedanför*, indicating that the influence of function is somewhat stronger on ratings of *under* than on ratings of *nedanför* as predicted, but this difference between preposition sets was non-significant across groups. However, as seen in section 2.4.1., across ratings of dynamic positions, ratings of *under* were significantly more sensitive to function than ratings of *nedanför*, which indicates that appropriate judgments about the prepositions are differentially influenced by function to a small degree.

5.3. SOURCES OF ERROR

As the present study is concerned with quite a number of factors, geometric as well as functional, there is a risk of confounding and the validity of some of the results might be questioned. For instance, as shown in section 5.1.2., geometric and functional factors at times predict similar patterns of ratings, and in such cases it is hard to conclude whether or not a functional effect is present. However, the overall rationale of the experiment ensures that the influences presented in section 4.2. cannot be accounted for by the geometric factors of importance according to the AVS-model. As geometric factors are held constant across control and experimental images and as functional manipulations are only present in the latter, any differences in ratings between control and experimental ratings have to be attributed to functional factors. Some of the problems associated with the extensive design of the experiment and other shortcomings of it are outlined in is this section.

5.3.1. The stimuli

The experiment was concerned with a number of functional factors, and the interaction variables yielded four possible interaction types, so in some cases it was hard to come up with the number of image sets needed to cover all the interaction types. Consequently, the interaction variables had to be defined somewhat loosely and the characteristics of the interactions varied across the image sets of some of the interaction types. For instance, the number and the locations of the dynamic positions varied across image sets for *Low precision/Centre-of-mass deviant Interactions*. Positions 3 to 5 were dynamic at both distances in the *hot dog/ketchup bottle* image set, whereas position 5 was only dynamic at a *Far* distance in the *glass/coke can* image set (see appendix 1). Also, only positions 4 and 5 were dynamic at both distances in the *water tap/glass* image set, whereas positions 3 and 4 were dynamic at both distances in the *can opener/tomato can* image set. Furthermore, across low precision images, it was either the form and function of the reference object or the located object that demanded a *Low precision Interaction*. For example, the interaction in the *hot dog/ketchup bottle* image set was fulfilled at multiple positions as ketchup could be poured at multiple positions along the upper side of the hot dog. Thus it was the functional characteristics of the reference object that demanded a *Low precision Interaction*. In the *water tap/glass* image set, on the other hand, the circumference of the glass was wide enough to allow the tip of the water tap to be vertically aligned with it at multiple positions and the interaction between the glass and the water tap could thus be fulfilled when the glass was positioned in more than one position below the tap. In the *water tap/glass* image set, it was therefore the functional characteristics of the *located* object that demanded a *Low precision Interaction*.

Such variation in the image sets of some of the interaction types is likely to make the patterns of ratings vary across image sets, which in turn make the general patterns in ratings of each interaction type less salient. With fewer image sets included in the experiment, the patterns of each interaction type might have been more pronounced. A possibility would have been to use only one set of each image type. However, the purpose of including several interaction types in the experiment was to explore how *general* characteristics of functional interactions influence patterns of ratings. If only one set per interaction had been used, the patterns obtained would have been specific for those particular interactions, whereas two sets permit some degree of generalization. Overall, the patterns in ratings of each interaction type did correspond to the predictions outlined in 3.1.3., despite the variation across image sets of each interaction type.

5.3.2. The experimental design

As discussed in section 3.1.4., each experimental group was concerned with one primary preposition, for which both experimental and control images were included, and one secondary preposition, for which only experimental images were included. Also, not all of the control sets included secondary control images; in the *ovanför* and *över* groups, only the control sets corresponding to centre-of-mass deviant image sets included secondary control images, whereas secondary control images were only available in the control sets corresponding to high precision/centre-of-mass deviant image sets in the *nedanför* and *under* groups. The reason for this was that it was the functional part of the reference objects that was disassociated from its centre-of-mass in the low precision/centre-of-mass deviant images of the *nedanför* and *under* image sets, not the functional part of the located objects, as it was hard to think of interactions for the *nedanför* and *under* groups.

The conditions were thus unevenly distributed within each group, which rendered the analysis of the data more difficult. Specifically, the complete set of data could not be analyzed within a comprehensive ANOVA model, and the ratings of the secondary prepositions as well as the secondary control ratings had to be excluded from the ANOVA displayed in table 5. Furthermore, several ANOVAs had to be conducted on subsets of the data. For example, to test if *Prototypicality* had a significant impact on ratings, an ANOVA conducted across experimental ratings only had to be conducted to include the ratings of the secondary prepositions as well (see section 4.2.3.). Also, the analysis of secondary control ratings had to be done across centre-of-mass deviant/low precision and centre-of-mass deviant/high precision ratings, respectively (see section 4.3.). Thus the unbalanced design of the experiment rendered the data difficult to analyze, and the validity of some of the significant effects of the experiment might be questioned, as they only emerged in analyses of parts of the data.

A far more serious flaw of the experiment, mentioned in section 3.3.3., is that the image order was not counterbalanced across subjects. The results might thus suffer from priming effects. That is, a specific image might influence the rating of the following image in some specific way. With a balanced design, such priming effects on ratings would be evened out as the image order is different for each subject. Also, the average time needed to finish the experiment was estimated to roughly 45 minutes (see section 3.1.4.). However, many of the subjects took much longer to finish, and some of them spent up to an hour and a half with the experiment. It is therefore possible that some of the subjects lost their focus and stopped paying attention to the task because of weariness. However, one purpose of the filler images included in the experiment was to see if subjects complied with the task at hand (see section 3.1.4.). As the sentences in the filler images always served as inaccurate descriptions of the images, subjects that were attentive to the task were expected to give low ratings to them. The overall mean of the filler ratings was very low (M = 1.94, SD = 2.05), and the average ratings of filler images exceeded 3.5 for five subjects only, which suggests that the majority of the subjects complied with the task despite of the long time needed to complete it.

5.4. A FURTHER EXTENSION OF THE AVS-MODEL

The results of the present study confirm for Swedish what has been shown in a number of studies concerned with English projectives, some of them outlined in section 2.4. As discussed in section 2.5., the results of these studies have shown that theories of the meanings of projective prepositions that only take geometric factors into account are inadequate, as judgments about the applicability of projective prepositions are also influenced by functional factors. The results of the present study confirm this and clearly show that a theory of the meanings of projective prepositions needs to take into account multiple source of information of both a geometric and functional nature.

Two such accounts were presented in section 2.5: the extended version of the AVS-model and the functional-dynamic framework. As discussed in section 5.1.3., the extended version of the AVS-model is unable to explain some of the results of the present study, as these results show that judgements about the acceptability of projectives are influenced by the functional part of the located object. Coventry & Garrod (2004) further claim that the extended version is an inadequate account of the meanings of projectives, as it cannot explain the functional influences of the Coventry et al. (2001) study. That study showed that ratings of projectives are influenced by functional factors, independent of geometric factors. They claim that this shows that functional influences have to depend on processes distinct from the computational process of the AVS-model, and that the meanings of projectives depend on two separate computational processes, one that deals with geometric relations, and one that is concerned with force-dynamic interactions. In their functional-dynamic framework, these processes are weighted and integrated within a situation model, based on the situation-specific context (see section 2.5.2.). However, the suggestion of the present work is that the geometric computation of the AVS-model is adequate to account for the results of the present work as well as the results of the Coventry et al. (2001) study if it takes into account knowledge about the shape and function of both the reference and located object, as well as the direction of potential motion. There is therefore no need to assume that geometric and functional influences depend on distinct processes. This further extension of the AVS-model is outlined in this section.

Acceptability judgments about projectives depend on the alignment between a vector sum orientation and a reference orientation of one of the axes of the reference frame, according to the AVS-model (see section 2.3.5.). The vector sum orientation is computed by the summation of a number of weighted vectors rooted across the reference object and projected towards the located object. The strength and positions of the vectors are determined by an attentional beam centred on the part of the reference object closest to the located object, and the size of the beam depends on the distance between the objects, as illustrated in figure 5. The model predicts that acceptability judgments about projectives depend on the shape of the reference object, the centre-of-mass and proximal orientation and the distance between the objects as confirmed by the results of the control ratings of the present experiment (see section 4.1.). The extension of the model presented in section 2.5.1. accounts for functional biases by additional attention paid to the functional part of the reference object. The functional part of the object is identified through concepts which provide a link between functional information in the conceptual system and the spatial representation of the object. The influence of the functional part of the reference object can then be accounted for by increasing the weight of the vectors rooted in that part. Consequently, those vectors will contribute more to the vector summation, and influence its orientation so that the peak position of the located object is biased towards the functional part. Although the model can account for the shape and the functional part of the reference object, it assumes that the located object schematizes to a point. However, as discussed in section 5.1.3., the results of the present study show that the shape of the located object influences judgments, and specifically, that the functional part of that object is of importance. Thus the position of that part has to be taken into account in the computational process.

The suggestion of the present work is that the vector summation does not only depend on knowledge of the shape and function of the reference object, but also on knowledge about the shape and function of the located object. Specifically, the point of the located object towards which the vectors are projected is determined by attention paid to the shape and the parts of that object. Thus any extra attention paid to the functional part of the located object will bias the position of the projection point towards its functional part.

This would account for those results of the present work that cannot be readily explained by the extended version of the AVS-model (see section 5.1.3.). In centre-of-mass deviant images in which the functional part of the located object is misaligned with its centre-of-mass, the point towards which the vectors are rooted will presumably be positioned in between the centre-of-mass of the located object and its functional part, as illustrated in figure 16. In the figure, the dotted lines represent vectors projected towards the centre-of-mass and the functional part of the located object, respectively. The functional part of the located object biases the position of the point towards which the vectors are projected to a position in between the centre-of-mass of the object and its functional part. Consequently, the vector sum orientations, labelled *a* and *b* in the figure, are intermediates of the axis projected towards the centre-of-mass of the located object and the axis projected towards its functional part. This would account for the functional bias in images where the position of the functional part is symmetric for the reference objects but asymmetric for the located objects, i.e., the low precision/centre-of-mass deviant images (see sections 4.2.2. and 5.1.3.). As shown in figure 16, the vector sum orientation will be closer to upright vertical when the functional part of the located object is vertically aligned with the reference object, as the position towards which the vectors are projected is closer to the functional part of the object. That is, the vector sum orientation *a* in the figure is closer to upright vertical than the vector sum orientation *b*. It also accounts for the fact that the estimated regions of acceptability of the control estimates match the regions of acceptability of the experimental ratings of centre-of-mass deviant images (see sections 4.3. and 5.1.3.). As the control estimates are combinations of ratings of the position of the centre-of-mass of the located objects and ratings of the position of their functional parts, they are an estimate of ratings of images in which vectors are projected towards a position in between the functional part of the located object and its centre-of-mass. The match between the control estimates and the experimental ratings thus gives support for this suggestion.

The strength of the bias of the projection point towards the functional part further depends on the salience of the functional interaction between the objects in the scene. Thus the functional bias will be stronger for functionally related objects than for functionally unrelated objects, which is in line with the results of the present study (see section 4.2.3.) and a number of earlier studies (see section 2.4.2.), the results of the second experiment of the Carlson-Radvansky et al. (1999) in particular.

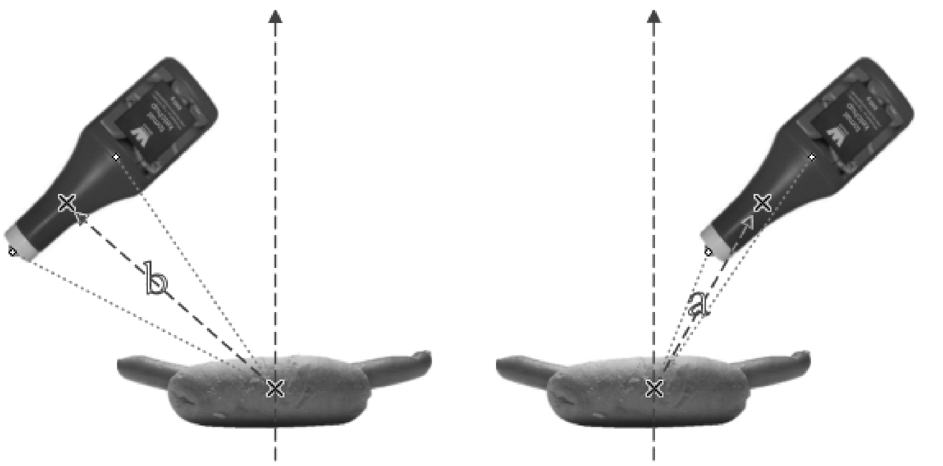


Figure 16. The extension of the AVS-model in the present work can account for influences of the functional part of the located object by assuming that the position of the point towards which the vectors are projected is determined by attention paid to the shape and the parts of the object. Any extra attention paid to the functional part of the object will bias the position of that point towards the position of the functional part and this bias is mediated by the strength of the functional interaction in the scene. Although attention is evenly distributed across the reference object, the vector sum orientation *a* is closer to upright vertical than the vector sum orientation *b*, as the position towards which vectors are projected is biased towards the functional part of the located object.

Finally, following Regier (1996); (see section 2.4.1.), the direction of potential motion can be used as yet another reference orientation in addition to the axes of the reference frame. Importantly, the choice of reference orientation depends on knowledge about the functions of the objects in the scene and knowledge about the situation-specific interaction. With the direction of potential motion incorporated as a potential reference orientation, the results of the Coventry et al. (2001) study mentioned above and discussed in section 2.4.1. can be accounted for. For example, this study showed that the acceptability of vertical projectives describing the relation between an umbrella and a man depended on whether or not the umbrella was protecting the man from rain, independent of the geometric relation between the man and the umbrella. These situations are illustrated in figure 17. According to the present work, knowledge about the function of the umbrella and the presence of rain in the scene will prime the direction of the motion of the rain, and that direction will be used as reference orientation. Thus, ratings of vertical projectives will be higher for image *a* in figure 17 in which the umbrella protects the man from rain than for image *b* in which the umbrella fails to protect the man, as the orientation of the path of the rain is closer to the vector sum orientation in image *a* than in image *b*. Had the umbrella been another object that did not serve a protecting function, the direction of the motion of the rain would have been of less importance, and upright vertical had been used as reference orientation.

Figure 17. The pictures of a man protecting himself with an umbrella, reproduced from Coventry et al. (2001). The suggestion of the present work is that the function of the umbrella and the presence of rain prime the direction of the motion of the rain and this is used as reference orientation. The acceptance of vertical projectives describing the relation between the man and the umbrella is higher for situation *a* than for situation *b* as the direction of the path of the rain corresponds to the vector sum orientation in situation *a*, but not in situation *b*.

5.5. SUMMARY AND CONCLUSIONS

The present work has been concerned primarily with a subclass of locative prepositions, the projective prepositions, which specify the position of a located object with respect to a direction in three-dimensional space relative to a reference object (section 2.1.). Traditionally, the projective prepositions have been regarded as expressing simple schematic relations of a geometric nature by referring to a direction of an axial structure defined with respect to the frame of reference or perspective adopted on the scene. According to this view, information about the shape of the related objects is abstracted away by projectives and the reference object is schematized to an axial structure and the located object to a point coincident with its centre-of-mass (section 2.2.).

The apprehension of projective relations involves a mapping between a spatial representation in the spatial system and a conceptual representation in the conceptual system, which is guided by the axial structure of the reference frame (sections 2.3. to 2.3.2.). The arguments of the conceptual representation of the expression are indexed in the spatial representation and the axial structure of the reference frame is adjusted on the object indexed as reference (section 2.3.3.). To determine the goodness-of-fit between the spatial relation in the spatial representation and a projective concept, a spatial template is imposed on the spatial representation (section 2.3.4.).

A spatial template is a vector representation, as generated within the AVS-model, which determines the goodness-of-fit between a spatial relation and a projective concept by comparing the vector sum orientation of the relation at hand with a reference orientation, which is the relevant axis of the reference frame. The vector sum orientation depends on the shape of the reference object, the centre-of-mass and proximal deviation as well as the distance between the spatially related objects (section 2.3.5.). Accordingly, the goodness-of-fit between a spatial concept and a spatial relation should depend only on these purely geometric factors. Empirical results show that this is in fact the case when the relation between the objects is strictly geometric. The present work confirms this by showing that acceptability judgments about Swedish vertical projectives also depend on these geometric factors when referring to purely geometric relations (sections 4.1. and 5.1.).

However, a number of studies have shown that the comprehension of spatial expressions in English involving projective prepositions also depend on the functional relation between the objects (section 2.4.). Much empirical evidence show that the comprehension and use of projective prepositions is influenced by the inferred or perceived force-dynamic interaction between the objects, and whether or not a threatening or protecting function is fulfilled (section 2.4.1.). Furthermore, judgments about whether a functional interaction is fulfilled often presuppose knowledge about the functions the objects afford and knowledge about how they typically interact, which has been shown to influence judgments about the acceptability of projectives (section 2.4.2.).

The present work shows that appropriate judgments about Swedish vertical projectives are also influenced by these functional factors. The comprehension of Swedish projectives is therefore not only influenced by function in the process of reference frame adjustment, as shown in a previous study (section 2.4.3.). The results of the present work show that acceptability judgments about Swedish vertical projectives are influenced by the inferred force-dynamic interaction between the spatially related objects, and more specifically, by whether or not one of the objects is fulfilling a threatening function (sections 4.2.1. and 5.1.2.). This further shows that acceptability judgments are influenced by knowledge about the functions of the spatially related objects, as judgments about whether the threatening functions are fulfilled presuppose such knowledge (section 5.1.2.). In order for a threatening function to be fulfilled in the experiment, the appropriate functional parts of the related objects had to be positioned in a manner that afforded their interaction. The results also show that acceptability judgments about Swedish vertical projectives are influenced by knowledge about whether or not the spatially related objects are functionally related (section 4.2.3.).

Knowledge about the functions of objects largely depends on the shape and the parts of those objects as objects are associated with affordances that relate their parts to potential interactions with them. Functional interactions between objects depend therefore on characteristics of the shapes and the functional parts of those objects such as the positions of those parts and the precision required for them to interact (section 2.4.5.). The present work explores how functional interactions depend on characteristics of the shapes and the parts of the related objects, and how such aspects influence acceptability judgments of projective prepositions (section 5.1.2.). The results of the experiment show how regions of acceptability are influenced in predictable manners based on characteristics of the shapes and the parts of the related objects (sections 4.2.2. and 5.1.2.).

Consequently, not only the shape of the reference object is of importance for functional interactions, but also the shape of the located object. This, in turn, entails that the form and function of both the reference and located objects influence acceptability judgments about projectives. The present work gives empirical support for the importance of the shape of the located object by showing that the functional part of the located object influences acceptability judgments about projectives (sections 4.2.2., 4.3. and 5.1.3.). Importantly, the present work shows that patterns in ratings of functionally related objects can be predicted from the joint influence of ratings of the position of the centre-of-mass of the located object and ratings of the position of its functional part (sections 4.3. and 5.1.3.).

Finally, a number of studies have shown that applicability of the English projectives *over* and *under* are more sensitive to functional influences than the corresponding projectives *above* and *below* (section 2.4.4.). The present work shows that acceptability judgments of the Swedish projectives *över* and *ovanför*, corresponding to *over* and *above*, respectively, are differentially influenced by functional factors in a similar manner to their English equivalents (sections 4.4. and 5.2.1.). However, acceptability judgments of *under* and *nedanför* are influenced by functional factors to the same degree, unlike the corresponding *under* and *below* (sections 4.4. and 5.2.2.).

The results of the present study confirm that the comprehension of projective prepositions depends not only on geometric factors but also on the functional interaction between the objects which in turn depends on the perceived or inferred force-dynamic interaction between the objects and knowledge about their functions. Thus a theory of the meanings of projective prepositions needs to take these factors into account (sections 2.5. and 5.4.). The extended version of the AVS-model deals with functional influences in terms of extra attention paid to the functional part of the reference object and can explain some of these functional influences, but is inadequate to account for some of the results of the present study (sections 2.5.1. and 5.1.3.) and cannot explain influences of functional factors when geometric factors are held constant (section 2.5.2.).

The suggestion of the present work is that a further extension of the AVS-model can explain the functional influences of the present study and of earlier studies by taking into account extra attention paid to the functional parts of both the reference and located object as well as the direction of potential motion, without assuming that geometric and functional influences depend on distinct processes (section 5.4.).

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Appendix

APPENDIX 1

List of the objects used in the experiment, for each set and experimental condition. Note, that within the *nedanför* and *under* images set, only the high precision images of the centre-of-mass deviant images have located objects for which the functional parts deviate from centre-of-mass. This is why secondary control images correspond only to high precision images within the *nedanför* and *under* image set.

ovanför* and *över

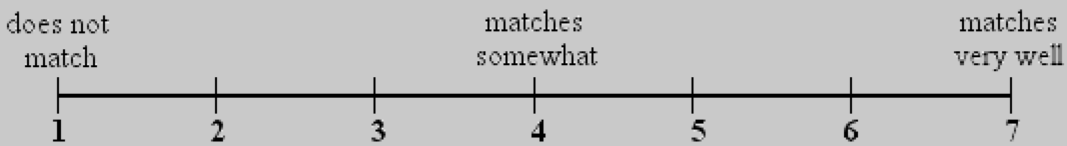
Set	Experimental condition	Reference object	Located objects: Prototypical	Located objects: Aprototypical
1	Low Precision Centre-of-mass Aligned	Coffee mug	Sugar cube	Ice cube
	Low Precision Centre-of-mass Deviant	Hot dog	Ketchup bottle	Toothpaste tube
	High Precision Centre-of-mass Aligned	Piggy bank	Coin	Ring
	High Precision Centre-of-mass Deviant	Petrol canister	Gas pump handle	Teapot
2	Low Precision Centre-of-mass Aligned	Trash can	Garbage	Ring
	Low Precision Centre-of-mass Deviant	Glass	Coke can	Tomato can
	High Precision Centre-of-mass Aligned	Wine bottle	Cork	Rubber
	High Precision Centre-of-mass Deviant	Finger	Nail polish	Paint brush

nedanför* and *under

Set	Experimental condition	Reference object	Located objects: Prototypical	Located objects: Aprototypical
1	Low Precision Centre-of-mass Aligned	Saw	Log	Swiss roll
	Low Precision Centre-of-mass Deviant	Water tap (kitchen type)	Glass	Coffee mug
	High Precision Centre-of-mass Aligned	Wine barrel	Wine carafe	Vase
	High Precision Centre-of-mass Deviant	Water tap (bathroom type)	Toothbrush	Pipe
2	Low Precision Centre-of-mass Aligned	Ketchup pump	French fries	Bowl of rice
	Low Precision Centre-of-mass Deviant	Can opener	Tomato can	Coke can
	High Precision Centre-of-mass Aligned	Ear	Earring	Fishing rod
	High Precision Centre-of-mass Deviant	Water pump	Watering can	Petrol canister

APPENDIX 2
An illustration of the start page of the experiment with the instructions translated into English.

You are about to perform an experiment which will take about 45 minutes. Your task is to rate on 7-grade scale how well you think sentences match different pictures. The scale goes from 1 to 7, where 1 means that you think that the sentence does not match the picture at all and 7 means that you think that the sentence matches the picture very well:



You report a value on the scale by pressing one of the keys 1 to 7 on your keyboard. Be careful to press the correct button, as you cannot go back and make changes if you press the wrong button. If you press any other button besides the number keys nothing will happen.

Once you have finished the experiment you will be informed if **you have won a cinema voucher, valued 100 SEK!**

Before the actual experiment starts, you will perform a test run to get acquainted with the procedure.

Thank you for your participation!

Your age: [ ]

Your sex: ○ Male ○ Female

Native tounge: ○ Swedish ○ Other

[Start the test run]

APPENDIX 3

An example of one of the experimental pages used in the experiment with all of the text translated into English.

State how well you think the statement matches the picture in accordance with the scale at the bottom of the screen:

The gas pump handle is above the petrol canister.

1	2	3	4	5	6	7
does not match			matches somewhat			matches very well