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Spatial language and converseness

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Typical spatial language sentences consist of describing the location of an object (the located object) in relation to another object (the reference object) as in "The book is *above* the vase". While it has been suggested that the properties of the located object (the book) are not translated into language because they are irrelevant when exchanging location information, it has been shown that the orientation of the located object affects the production and comprehension of spatial descriptions. In line with the claim that spatial language apprehension involves inferences about relations that hold between objects it has been suggested that during spatial language apprehension people use the orientation of the located object to evaluate whether the logical property of *converseness* (e.g., if "the book is *above* the vase" is true, then also "the vase is *below* the book" must be true) holds across the objects' spatial relation. In three experiments using sentence acceptability rating tasks we tested this hypothesis and demonstrated that when *converseness* is violated people's acceptability ratings of a scene's description are reduced indicating that people do take into account geometric properties of the located object and use it to infer logical spatial relations.

Keywords: Spatial language; Spatial relations; Inference; Converseness; Acceptability rating task.

Spatial language comprises part of the essential fabric of language. Words, such as *in, on, over*, and *in front of* are among the most frequent words in the English language and have the important role of informing a hearer about where objects are located. For example "The acrobat is *above* the chair" allows the hearer to constrain the search for the acrobat (the located object, LO) by locating her in relation to another known or easily identifiable object (the reference object, RO; Landau & Jackendoff, 1993; Regier & Carlson, 2001; Talmy, 1983). Much research has focused on the properties of the reference object showing, for example, that its orientation is critical for selecting a reference frame (Carlson, 1999; Carlson-Radvansky & Irwin, 1994; Carlson-Radvansky & Logan, 1997; Carlson & Van Deman, 2008), which could be based on the environment (absolute), on the viewer's point of view (relative), or on the reference object (intrinsic; Levinson, 1996a).

On the other hand, geometric properties of the LO, such as its orientation, have remained of

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secondary interest within the context of spatial language, where it has been claimed by some that the located object and its geometric properties are irrelevant for the understanding of spatial language (Jackendoff, 1983; Talmy, 1983). However, there is more recent evidence that properties of the LO do play a role within the domain of spatial language comprehension in English (Carlson-Radvansky & Radvansky, 1996; Coventry, Prat-Sala, & Richards, 2001; Feist, 2000; Feist & Gentner, 2012) and across languages (Brown, 1994; Levinson, 1996c; Valentine, 2001).

Recently it has been shown that people do process the orientation of the LO during the comprehension and the production of spatial language (Burigo & Sacchi, 2013). In this study, participants were asked to place the LO in the position indicated in a simple spatial description such as "A is *above* B" or to describe the location of two objects presented in a scene using a similar sentence structure. When the orientation of the LO did not match the orientation of the RO, both the action of placing the objects in the designated location and describing their location took longer than it did for the scene where the LO orientation matched the orientation of the RO. These results indicated that participants processed the orientation of the LO during the apprehension of spatial descriptions and that such information somehow conflicted with the information concerning the orientation of the RO. According to the observation that the orientation of the objects is critical for choosing the reference frames that people impose on the scene (Carlson-Radvansky & Irwin, 1994), the fact that people gathered the orientation information also for the LO suggested that they may have also considered a description where the LO is used as a reference. This is in line with the claim that a spatial description is accompanied by its converse description; so "A is *above* B" and "B is *below* A" are both acceptable descriptions of the same scene (Levelt, 1984).

In this paper we provide some evidence in support of the idea that the divergence between the orientation of the RO and the orientation of the LO is important for a specific type of inference that people make about the relations between the objects in the scene: *converseness*.

Converseness and spatial prepositions

Above–below, front–back, north–south are directional opposite pairs and therefore exhibit the property of converseness (Levelt, 1984, 1996) such that, if the two-place relation expressed by one pole is called R and the other R^{-1}, then $R(X, Y) \Leftrightarrow R^{-1}(Y, X)$. Hence if X is *above* Y, Y will be *below* X. This means that a spatial relation and its converse are both possible in describing the spatial relations between two objects. However, this is not always the case as there are situations where the property of converseness cannot be applied, as is the case with *in front of* applied within an intrinsic frame of reference. This spatial term accepts multiple reference frame interpretations (Levinson, 1996b), but when two objects with a clear intrinsic axis are horizontally aligned (as in Figure 1), judging the appropriateness of an *in front of* relation can only depend on the intrinsic reference frame. Empirical evidence supporting this view is discussed in a previous study (Burigo & Sacchi, 2013) where participants were asked to describe a similar set of stimuli to the ones used here. The outcomes revealed that the majority of people described the scene using the intrinsic perspective (less than 5% of participants used a relative description).

Accordingly, "The flamingo is *in front of* the dog" is an acceptable description for both Figures 1a and 1b. However, converseness holds in Figure 1b (where the converse description "The dog is *behind* the flamingo" is still a perfectly acceptable description for the scene) but not in Figure 1a, since "The dog is *behind* the flamingo" is not acceptable. This example illustrates how converseness might or might not hold for the simplest case—that is, where an intrinsic reference frame is the only available frame to judge the appropriateness of a spatial term (Levelt, 1996).

When we consider the case of vertical spatial relations the situation is more complex as people are likely to use a combination of absolute, relative, and intrinsic reference frames to judge the appropriateness of these spatial terms (e.g., Carlson-Radvansky & Irwin, 1993, 1994). In this case, multiple activated reference frames may compete with

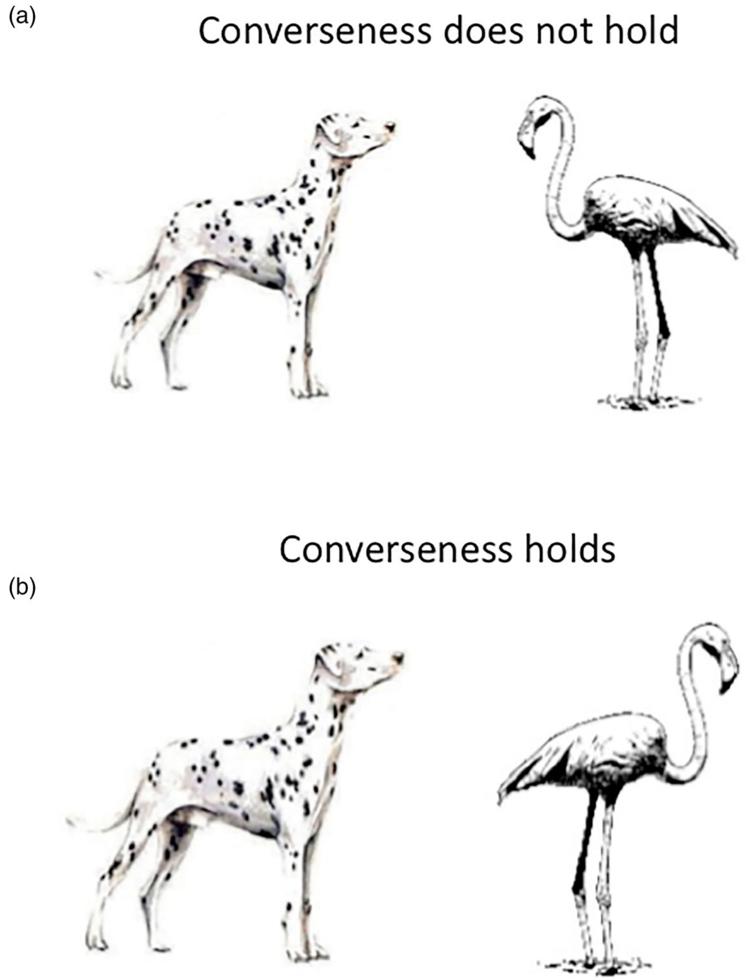

Figure 1. *In 1a and 1b the description "The flamingo is* in front of *the dog" is true. However in 1a converseness does not hold as the converse description "The dog is* behind *the flamingo" is false. In 1b converseness does hold as "The dog is* behind *the flamingo" is true.*

each other (Carlson & Logan, 2001; Carlson-Radvansky & Irwin, 1994; Carlson-Radvansky & Jiang, 1998; Carlson-Radvansky & Logan, 1997; Taylor & Rapp, 2004); therefore it is important to discuss also those cases where a violation of converseness occurs for a spatial term for which multiple reference frames are active (e.g., with *above/below*), which may not necessarily be the same as for those spatial terms that can be interpreted only using an intrinsic perspective (e.g., with *in front of/behind*). That said, it is critical to bear in mind that the property of converseness cannot be violated within an absolute or relative frame of reference (under normal circumstances, such as with the viewer's head upright) because from these perspectives if "A is *above* B" the converse description "B is *below* A" is always an acceptable alternative. It is only within an intrinsic reference frame that converseness can be violated, given that the computation of the spatial relation depends on the orientation of the reference object (instead of the orientation of the environment/viewer as for the absolute/relative frames).

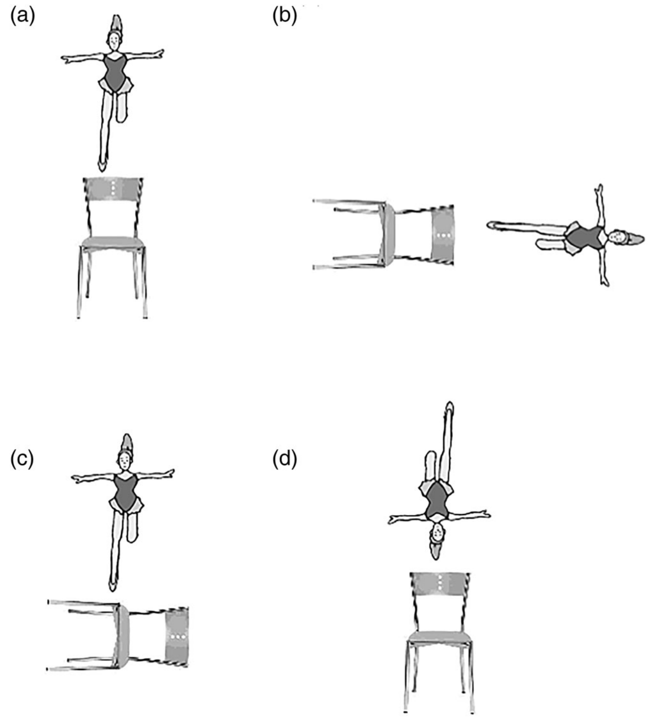

Figure 2. *In 2a "The acrobat is* above *the chair" is an acceptable description within the intrinsic, relative, and absolute reference frames. In 2b it is true for the intrinsic frame but not for the relative frame or absolute frames, and in 2c it is true for the relative and absolute frames but not for the intrinsic frame. Given the above spatial description, its converse ("The chair is below the acrobat") is an acceptable description for (a) and (c) regardless of which reference frame has been selected, while from the intrinsic perspective, it does not hold for (d) but it does in (b).*

For example, in Figures 2a and 2d "The acrobat is *above* the chair" is true, with respect to the viewpoint of the viewer (or relative reference frame), with respect to the orientation of the chair (or the intrinsic frame; the acrobat is higher than the top part of the chair), and with respect to the gravitational plane (the absolute frame). However, according to the intrinsic reference frame converseness holds in Figure 2a since "The chair is *below* the acrobat" is an acceptable description, but not in Figure 2d since the converse description does not apply (i.e., the chair, from the intrinsic reference frame is above the acrobat, not below). In Figure 2b, "The acrobat is *above* the chair" is acceptable only within the intrinsic frame of reference (i.e., with respect to the axes defined by the RO), but is unacceptable with respect to the relative (viewer-centred) or absolute (gravitational) frames. In this case (within the intrinsic reference), converseness holds since its converse description "The chair is *below* the acrobat" is a valid specification. In Figure 2c, "The acrobat is *above* the chair" is acceptable within the relative and absolute frames, but is false within the intrinsic frame, where a more appropriate description of the scene would be "The acrobat is *on the left* of the chair". According to this description, based on the intrinsic perspective, converseness does not hold since the converse description "The chair is *on the right of* the acrobat" does not apply to this scene. These examples show that for acceptable spatial descriptions based on vertical spatial terms (*above, below, over,* and *under*), deciding whether the logic of converseness can or cannot be applied depends exclusively on intrinsic interpretation, as it is the only frame that is sensitive to changes in the orientation of the located object.

Inferences in language

The possibility that the effect of the orientation of the located objects observed in Burigo and Sacchi (2013) was due to the property of *converseness* is consistent with previous work showing that producing and interpreting a spatial description involves speakers attempting to construct the most informative spatial model that associates the objects involved (Coventry & Garrod, 2004; Tyler & Evans, 2003). For example, expressions such as "The bottle is *over* the glass" allow the hearer to infer that the bottle and glass are in an interactive situation where liquid in the bottle will end up reaching the glass. The actual or potential path of falling liquid from the mouth of a bottle affects the extent to which the bottle can be described as *over* or *above* the glass, even when geometric positions remain constant (Coventry et al., 2001). Furthermore when participants are shown static images of bottles beginning to pour liquids (without showing the liquid missing/entering the glass), participants' eye gaze patterns reveal that they look at the potential end path of falling objects before they return their spatial language judgements (Coventry, Christophel, Fehr, Valdés-Conroy, & Herrmann, 2013; Coventry et al., 2010) suggesting that participants inferred whether the liquid would end in the container. Carlson-Radvansky and Tang (2000) also found that when objects were functionally related (e.g., a ketchup bottle and a hotdog), participants rated *above* descriptions more highly for scenes where the bottle (the LO) was tilted rather than presented in an upright (canonical) position consistent with the situation affording maximum interaction. These results are part of a much larger body of empirical findings showing that object knowledge and situational information are used to generate inferences that affect language comprehension and production (see Coventry & Garrod, 2004, for a comprehensive review).

Applying these principles to spatial language, we expect the hearer to infer the spatial relations between the objects concerned and build the best model—that is, one that supports the strongest inferences about the relations between the objects in the scene. Thus, if it is true that the orientation of the LO is relevant because it allows one to apply the property of converseness, then the use of spatial expressions where converseness should apply but does not may be regarded as poorer descriptions of spatial scenes than spatial descriptions where converseness does apply for those spatial expressions. In other words, descriptions of spatial scenes that maintain the property of converseness should be better descriptions of the scene than those descriptions where converseness is violated. Then, according to the pragmatic principle that people should always produce the most informative description (the Q-principle; Levinson, 2000; see also Asher & Lascarides, 2003), a spatial description should be considered less informative (and therefore less acceptable) when referring to a scene where converseness does not hold.

In the present paper we aim to investigate whether the converseness hypothesis is a valid explanation for the effect of the located object's orientation on the comprehension of scene descriptions observed in Burigo and Sacchi (2013). Furthermore, we try to replicate Burigo and Sacchi's effect using a different methodology: an acceptability rating task (Carlson-Radvansky & Irwin, 1993, 1994), which should better capture the effects of reduced informativeness for scenes where converseness does not hold. The experiments examine whether the presence or absence of converseness affects spatial language comprehension across two sets of spatial relations. Experiment 1 focuses on relations on the horizontal axis only (*in front of* and *behind*), which represent a simple case where the intrinsic reference frame is the only system used to decide whether the spatial term matches the spatial relation. In fact, as discussed above, the use of side-view objects limits the influence of the absolute and relative reference frame.

In Experiment 2 we investigate spatial prepositions on the vertical axes (*above/below*) while we manipulate the reference frame selection process in order to disentangle whether a violation of converseness occurring at the intrinsic level can still affect the acceptability of a spatial relation whose acceptability depends also on the absolute and relative reference frames (cases where converseness always hold). In Experiment 3 we test the converseness hypothesis using objects that do not show extra cost in recognition time when they are rotated (so called *polyoriented* objects; Leek, 1998a) in order to show that converseness effects do not depend on an identification cost for the objects shown in the scenes. To preview the results, we report evidence that judgements of the extent to which spatial expressions map onto pictures are affected by converseness.

EXPERIMENT 1

In this experiment we set out to test whether the presence/absence of converseness affects acceptability for sentences containing *in front of/behind* to describe simple line-drawn spatial scenes. In particular we hypothesized that acceptability ratings for spatial expressions containing *in front of/behind* to describe scenes where converseness holds (e.g., Figure 1b) would be higher than for those scenes where converseness does not hold (e.g., Figure 1a).

Method

Participants

Twenty students (14 females and 6 males; age range from 18 to 44 years, mean age = 22 years) participated in this study for course credit. All participants were native English speakers with normal or corrected-to-normal vision.

Design and materials

This experiment employed an acceptability-rating task where participants had to rate the acceptability of sentences containing the spatial prepositions *in front of* and *behind* to describe pictures. Eight objects were used, all with clear front/back orientations when presented in profile (e.g., dog, frog, penguin, etc.; see Appendix for the complete list). Each scene consisted of a pair of objects (e.g., two dogs), with the RO and LO distinguished by four different colours. The scenes were described by sentences of the form "The LO is PREPOSITION the RO" (e.g., "The black dog is *behind* the white dog"). Objects were always positioned along the horizontal axis placed either 9 cm or 12 cm apart (on a 17″ monitor) and were positioned facing either to the left or to the right, with the LO positioned to the left or right of the RO (see Figure 3 for examples). The placement of the object pairs was randomized to different screen positions to prevent participants from seeing objects in predictable locations.

The design included the following factors: 2 (preposition; in front of vs. behind) × 2 (distance; near vs. far) × 2 (converseness; present vs. absent). The distance manipulation was incorporated into the design as it has been shown that distance can modulate the acceptability of some spatial descriptions (Coventry et al., 2001; Hayward & Tarr, 1995; Regier & Carlson, 2001). More specifically, the distance between the LO and RO is inversely proportional to the acceptability of a spatial relation as reflected in the spatial template activated for the given spatial term (Carlson-Radvansky & Logan, 1997): When the LO is placed farther away from the RO the acceptability is reduced (but only when the LO is not vertically aligned with the RO). Given that the effect of distance reflects different spatial template shapes (Carlson-Radvansky & Irwin, 1994), it was important to assess whether it has an effect on the applicability of converseness.

Orientation of the RO, object colours, and locations of the LO were counterbalanced within participants, resulting in a total of 512 stimuli. Half of all trials were true, and half were false. A scene was false when the located object's location did not match the one expressed in the description. For example, given the scene in Figure 3a, the description "The white dog is *behind* the black dog" was false.

Procedure

Participants had to judge the appropriateness of a sentence of the form "The LO is PREPOSITION the RO" to describe a picture that followed immediately afterwards. Participants pressed the space bar after they read each sentence to reveal the associated picture. When ready, participants gave their judgements by pressing a

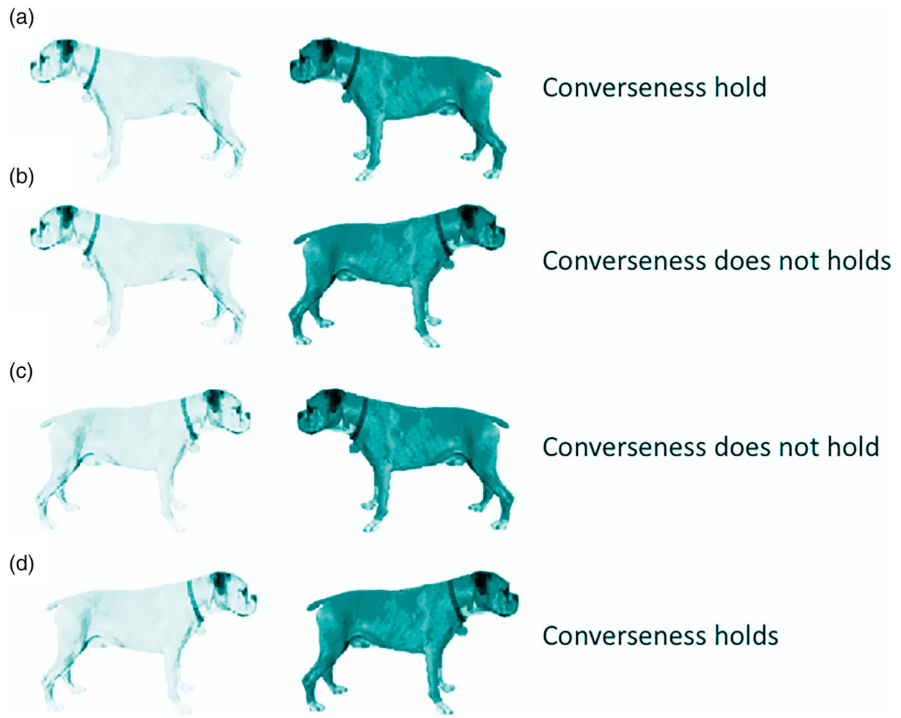

Figure 3. *Examples of object pairs used in Experiment 1. The same items with different colours were used in order to control for frequency effects and word length that could originate from using different item labels.*

number between 1 and 9 (where 1 = not at all acceptable, and 9 = perfectly acceptable).

Results and discussion

The mean acceptability ratings for true instances of *in front of* and *behind* by distance and converseness (present or absent) are displayed in Table 1. The data were analysed using a 2 (preposition; in front of vs. behind) × 2 (distance; near vs. far) × 2 (converseness; present vs. absent) within-participants analysis of variance (ANOVA). The results revealed a main effect of preposition, $F(1, 19) = 7.96$, $MSE = 0.71$, $p = .01$, $\eta_p^2 = .293$. Overall ratings for *in front of* were significantly higher ($M = 7.39$) than those for *behind* ($M = 7.02$). There was also a main effect of converseness, $F(1, 19) = 8.07$, $MSE = 13.75$, $p = .01$, $\eta_p^2 = .298$. When converseness was present, ratings were significantly higher ($M = 8.04$) than when converseness was not present ($M = 6.36$). There was no main effect of distance, nor any interactions between any of the factors. The lack of an effect of distance is in line with previous results showing that distance does not affect the acceptability rating for a spatial relation when the LO is aligned with the RO (Carlson-Radvansky & Logan, 1997).

Table 1. *Mean acceptability ratings as a function of preposition, distance, and converseness in Experiment 1*

Spatial Preposition × Distance	*Converseness present*	*Converseness absent*
In front of		
Near	8.09 (1.59)	6.62 (1.95)
Far	8.07 (1.57)	6.78 (1.91)
Behind		
Near	8.06 (1.56)	6.03 (2.28)
Far	7.94 (1.63)	6.06 (2.25)

Note: Standard deviations in parentheses.

These results support the view that the presence of converseness in a visual scene increases people's acceptability judgements of the spatial descriptions used to describe that scene. This suggests that people may use the property of converseness as a means of gauging the informativeness of scene descriptions. However, this study addresses only one set of spatial relations (*in front of* and *behind*), which operate only within a single spatial axis (i.e., the horizontal axis), and their interpretation depends, at least in the way they are displayed in our study, exclusively on the intrinsic reference frame. In Experiment 2, we demonstrate that the importance of converseness in communicating spatial information extends to additional spatial relations (e.g., *above, below*) and to other spatial axes (i.e., the vertical axis), and affects spatial description comprehension also when multiple reference frames are in play.

EXPERIMENT 2

This experiment set out to test whether the effect of converseness occurs also with the vertical spatial prepositions *above* and *below*. As described before, with these prepositions the computation of converseness can be more complex as people may ground their judgements using all three reference frames or just a selection depending on the orientation of the RO. In particular, with respect to these spatial terms, converseness violation occurs when the LO is rotated, as in Figure 2d. Here "The acrobat is *above* the chair" is true for all three reference frames, but converseness is violated within the intrinsic reference frame: The chair is not below the acrobat's head. Experiment 1 has already shown that converseness is important in the case where the acceptability of a description depends on the intrinsic frame, but whether this is also the case even when other reference frames are applied remains to be established. Accordingly, in addition to manipulating converseness via the degree of rotation of the LO, in this experiment we crossed this with manipulating the orientation of the RO. This was important in order to disentangle whether a violation of converseness within the intrinsic reference frame still affects the overall acceptability for the given spatial relation, or whether the fact that converseness holds for the relative and the absolute reference frames makes the violation undetected.

Method

Participants

Twenty-five students (21 females and 4 males; age range from 18 to 53 years, mean age = 21 years) participated in this study for course credit. All the participants were English native speakers with normal or corrected-to-normal vision.

Design and materials

The variables in this study were the following: 2 (superior/inferior prepositions: above vs. below) × 2 (distance: far vs. near) × 4 (orientations for the LO) × 4 (orientations for the RO). The location where the LO could appear in relation to the RO was manipulated in order to present the objects at two different distances. Figure 4 shows examples of the 10 locations where the LO appeared around the RO: 5 locations above the RO and 5 locations below the RO. Locations 3 and 8 were included for completeness (for an extra 64 trials), but not as a level of orientation for subsequent analyses because under some conditions "vertical" and "pointing at" orientations are the same. Locations of the LO and stimuli sets were balanced within participants, resulting in a total of 624 stimuli.

In this experiment we used "vertical", "pointing at", "90° away" (pointing away from the other object), and "90° at" (pointing towards the other object) orientations for the LO and the RO: These orientations were selected because they allowed us to test all possible degrees for which converseness holds while testing the strongest case in which converseness does not hold (that is, when objects' axes are aligned but have opposite directions). Figure 5 illustrates the orientations used. In the "pointing at" conditions, the axis of the LO was pointing exactly towards the centre of mass of the RO and vice versa.

Critical objects had a well-defined intrinsic axis (or oriented axis objects); these are objects with a "head" and a "tail" (e.g., a chicken, a hat, a vase, etc.). These types of objects were used as LO as

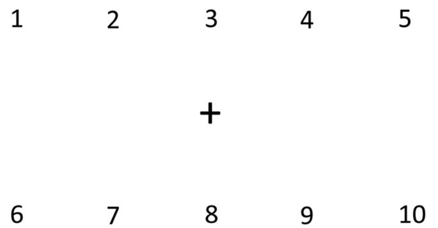

Figure 4. *The figure illustrates the 10 locations of the located object (LO) around the reference object (RO; the "+" in the middle). Locations 1, 5, 6, and 10 were far locations: 2, 4, 7 and 9 were near locations. The orientations for the "pointing at" conditions were as follows: 1 = 116°, 2 = 139°, 3 = 180°, 4 = 221°, 5 = 244°, 6 = 64°, 7 = 41°, 8 = 0°, 9 = 319°, 10 = 296°. The orientations for the pointing away conditions were these values + 180°.*

well as RO. In addition two further types of objects were used as LOs for filler trials: 24 non-oriented axis objects (such as an hourglass) and 24 no axis objects (such as a wheel; see Appendix for the complete list).

The assessment of converseness assessment for vertical spatial terms

A spatial description referring to a vertical spatial relation, such as *above* or *below*, is subjected to the influence of multiple reference frame (Carlson-Radvansky & Irwin, 1993, 1994). Therefore it is critical for this study to describe how converseness is assessed in such context. First of all, we focus on those trials where the provided description was good/acceptable according to all reference frames. This follows the principle that people should apply the inference of converseness only on valid descriptions because if the sentence is invalid then there is no need to carry on any further processing.

Figure 5 shows all the possible orientation combinations (but not all possible locations) for descriptions including *above* (left panel) and *below* (right panel). These two sentences are, from the absolute/relative reference frame, all perfectly acceptable, and so are their converse descriptions, given that the LO (the cat) is always above (or below, in the right quadrant) the grazing line (Regier & Carlson, 2001) set on the RO (the pan), which is what people use to differentiate a "good/acceptable" region from a "bad" region (Carlson-Radvansky & Irwin, 1994). When referring to an intrinsic reference frame, this is not always the case. As illustrated in Figure 5, scenes for which the sentence is valid are those without boundaries. These are the scenes presenting the RO with a "90° away" orientation associated with the description "The cat is *above* the pan" (left panel). For *below* scenes (right panel), the description "The cat is *below* the pan" is unacceptable for the scenes with the RO "pointing at" and "90° at" orientations. Once we have described how a valid and an invalid description is assessed within an intrinsic reference frame, we can now move on identifying cases where converseness is violated according to the simple "The cat is *above* the pan—then—the pan is *below* the cat" rule. In Figure 5, these are the scenes with a dashed frame. Scenes where the description is valid, and converseness applies are coded with a solid line frame. All the results and the interpretation of the effects of the orientation of the LO described in the paper are based on this coding procedure.[1]

Procedure

The procedure was the same as that used for Experiment 1.

[1]Since the coding relies on the assumption that participants compute converseness as described in Figure 5, we ran an additional study where 11 participants had to rate the appropriateness of two opposite descriptions referring to the same scene (e.g., "The cat is *above* the pan" vs. "The pan is *below* the cat") in order to check that the assignment of cases where converseness does and does not hold is corroborated with impartial participants' judgements. For the valid cases in Figure 5 we calculated a "converseness factor" (CF) by subtracting the rating for a description (e.g., "The cat is *above* the pan") from that for its converse description (e.g., "The pan is *below* the cat"). The statistics revealed a significantly higher CF difference for the scenes where converseness did not hold ($M = 3.33$, $SD = 1.09$) than for scenes where converseness held ($M = .35$, $SD = .51$) both in *above*, $t(10) = 12.11$, $p < .001$, and in *below* descriptions, $t(10) = 7.85$, $p < .001$. In addition for cases where converseness held, there was no significant difference, $t(10) = 0.3$, $p = .77$, between the ratings for higher ($M = 4.17$, $SD = 0.56$) and lower relation ($M = 4.14$, $SD = 0.47$), but there was for cases where converseness did not hold, $t(10) = 2.59$, $p < .05$ ($M_{\text{above}} = 3.3$, $SD = 0.36$; $M_{\text{below}} = 3.04$, $SD = 0.46$). These outcomes confirmed that participants presented the same assessment of converseness (where it holds and does not hold) as the one described in Figure 5.

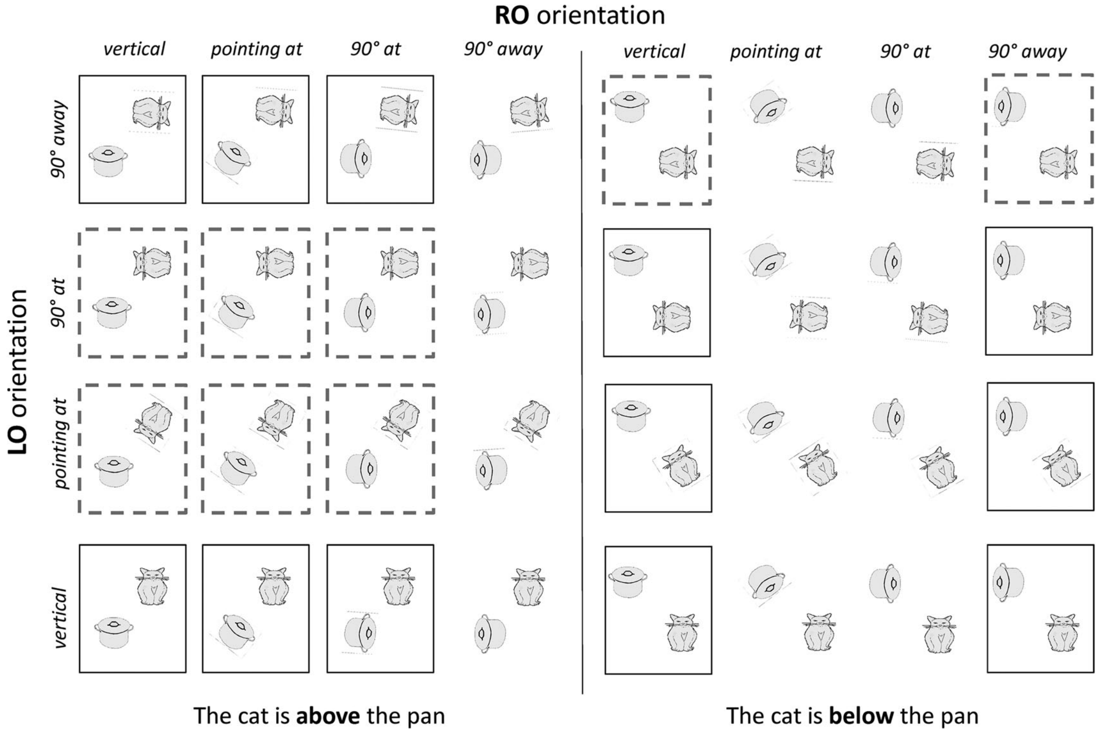

Figure 5. *Examples of scenes used in Experiment 2. LO = located object; RO = reference object. Scenes without boundaries are those for which the description is invalid for an intrinsic reference frame interpretation. Scenes with a dashed frame identify the cases where the description is valid but converseness is violated. Finally scenes with a solid line frame are those for which the description is valid and converseness holds.*

Results and discussion

The analysis focused on the oriented axis objects, as these are the only objects that allow the manipulation of converseness based on the intrinsic reference frame. Furthermore, only scenes where the given spatial description was valid across all the reference frames were analysed, excluding then those cases where a description may be valid from an absolute/relative reference frame but not for the intrinsic perspective (see Figure 5).

Table 2 reports the mean acceptability ratings and standard deviations [collapsed by side, as no effect was found for this variable; $t(24) = -0.846$, $p = .406$] for combinations of LO and RO. The acceptability ratings were submitted to a 2 (prepositions; above vs. below) × 2 (distance; near vs. far) × 4 (orientations of the LO) × 4 (orientation of the RO) repeated measures ANOVA. A summary of means for all the factors can be found in Table 2.

First we report the effects involving the orientation of the LO as they provide evidence for the importance of converseness for terms on the vertical axes. There was a main effect of the orientation of the LO, $F(3, 72) = 3.78$, $MSE = 1.69$, $p < .014$, $\eta_p^2 = .136$, and there was also a significant interaction between preposition and the orientation of LO, $F(3, 72) = 2.98$, $MSE = 2.45$, $p < .036$, $\eta_p^2 = .111$. For *above*, ratings for the "vertical" ($M = 6.86$) and "90° away" ($M = 6.77$) orientations—orientations where converseness holds—were significantly higher than for the "90° at" the RO ($M = 6.50$) and the "pointing at" the RO ($M = 6.43$) orientations (both $p < .05$)—orientations where converseness is violated. For *below*, the "vertical" (M = 6.63) and "pointing at" ($M = 6.54$) orientations—orientations where converseness holds—

Table 2. *Mean acceptability ratings for combinations of the RO and LO in Experiment 2*

Spatial Preposition × Distance × LO Orientation			*RO orientation*			
			Vertical	*Pointing at*	*90° at*	*90° away*
Above	Far	*Vertical*	6.92 (1.63)	6.58 (1.95)	5.8 (2.52)	6.86 (1.75)
		Pointing at	6.11 (2.04)	6.4 (1.75)	5.77 (2.36)	6.25 (2.06)
		90° at	6.6 (1.67)	6.8 (1.76)	6.25 (2.1)	6.45 (1.86)
		90° away	6.17 (1.86)	6.52 (1.9)	5.98 (2.17)	5.98 (1.95)
	Near	*Vertical*	7.19 (1.88)	7.21 (1.76)	6.86 (1.91)	7.21 (1.52)
		Pointing at	7.06 (1.84)	7.02 (1.76)	6.03 (2.69)	7.1 (1.22)
		90° at	7.1 (1.67)	7.15 (1.77)	6.8 (1.98)	7.13 (1.74)
		90° away	6.77 (1.85)	6.76 (2.09)	6.23 (2.51)	6.8 (2.05)
Below	Far	*Vertical*	6.8 (1.75)	5.9 (2)	6.3 (1.9)	5.8 (2.03)
		Pointing at	6.48 (1.74)	5.9 (1.92)	6.33 (1.84)	5.78 (2.28)
		90° at	6.5 (1.52)	5.9 (2.42)	5.9 (2.07)	5.53 (2.31)
		90° away	6.65 (1.95)	5.58 (2.11)	6.17 (2.3)	5.9 (1.73)
	Near	*Vertical*	7.45 (1.55)	6.47 (2.21)	7.19 (1.65)	7.05 (1.91)
		Pointing at	6.56 (2.02)	6.55 (2.02)	7.21 (1.78)	6.6 (2.09)
		90° at	6.52 (2.2)	5.96 (2.61)	6.66 (1.95)	6.78 (2.13)
		90° away	7.35 (1.7)	6.6 (2.18)	7.18 (1.77)	6.72 (2.04)

Note: The reference object (RO) and the located object (LO) were always objects with an oriented axis. Standard deviations in parentheses.

were rated significantly higher than the "90° away" orientation ($M = 6.25$; both ps $< .05$)—the orientation where converseness does not hold. None of the other effects or interactions were significant, and interestingly there were no significant interactions involving orientation of the RO and orientation of the LO (all Fs < 1).

We also found a significant main effect of spatial preposition, $F(1, 24) = 6.7$, $MSE = 1.64$, $p < .016$, $\eta_p^2 = .218$, and of distance, $F(1, 24) = 30.63$, $MSE = 5.46$, $p < .00001$, $\eta_p^2 = .561$. *Above* received higher ratings ($M = 6.63$) than *below* ($M = 6.47$), and scenes where the LO was positioned near the RO received higher ratings ($M = 6.88$) than scenes where the LO was far from the RO ($M = 6.23$). The distance effect was in line with that in previous studies (Coventry et al., 2001; Hayward & Tarr, 1995; Regier & Carlson, 2001) showing that in scenes where the LO is not vertically aligned with the RO (as in this experiment) acceptability ratings were inversely proportional to the distance between the objects. The lack of an interaction between distance and the orientation of the LO suggests that the converseness inference is indifferent to the information about the distance between the two objects.

There was a main effect of the orientation of the RO, $F(3, 72) = 4.69$, $MSE = 1.71$, $p < .004$, $\eta_p^2 = .164$. The RO in the "vertical" orientation received significantly higher ratings ($M = 6.76$) then the RO presented with a "pointing at" and "90° at" orientation (both $M = 6.51$) and "90° away" orientation ($M = 6.44$; all ps $< .01$). There was also a significant interaction between preposition and orientation of the RO, $F(3, 72) = 4.34$, $MSE = 4.94$, $p < .007$, $\eta_p^2 = .153$. For *above*, when the RO was pointing "90° away" from the LO ($M = 6.26$), ratings were significantly lower than for any of the other orientations as expected ($p < .05$). This is because when the RO faces away from the LO *above* is false in the intrinsic frame, and the ratings are therefore lower than for the other orientations where *above* is true for both the intrinsic and relative frames. For *below*, ratings for the "vertical" ($M = 6.8$) and the “90° away” ($M = 6.62$), orientations were significantly higher than those for the “90° at” ($M = 6.18$) and “pointing at” ($M = 6.30$) orientations ($p < .04$). Again these differences reflect the extent to which *below* is true in both intrinsic and relative frames. The effects found for the orientation of the RO are consistent with results found previously (e.g., Carlson-Radvansky & Irwin, 1994). When the spatial preposition maps onto a good region in both the intrinsic and relative frames, ratings are higher than when the preposition is appropriate only within a single reference frame.

In summary, the effects of the orientation of the LO are consistent with the results of Experiment 1. Rotating the LO such that it is pointing at the RO (that is, the strongest case where converseness does not hold) is associated with lower ratings for *above* than when the LO is vertical or facing away from the RO (that is, the case where converseness holds). Vice versa, while rotating the LO such that it is pointing away from the RO (that is, the case where converseness does not hold) is associated with lower ratings for *below* than when the LO is vertical or pointing at the RO (that is, the case where converseness holds). The presence of a converseness effect in both Experiment 1 (where only an intrinsic reference frame was in play) and Experiment 2 (where a combination of reference frames are likely to have been assigned) is a clear indicator that converseness affects the acceptability of a spatial description regardless of which reference frame has been applied on the scene.

The lack of an interaction between the orientation of the RO and the orientation of the LO is not in contradiction with the results shown in Burigo and Sacchi (2013), where the effect of the orientation of the LO has been measured in relation to the degree to which the orientation of the LO and the RO match regardless of the orientation of the RO. In fact in this study, the non-canonical orientation was always the diametrically opposite direction (180° difference: so if the RO was 0° the conflicting orientation was 180°; if the RO was 90°, then the LO was 270°), while in Experiment 2 of the current study only 3 (or 6 if we consider both spatial terms) out of 16 (or 32 including also below cases) scenes—that is, only 18.75% of all the possible RO and LO orientation combinations—presented such contrasting orientations. Then, out of the 13 remaining scenes, 2 had the RO and LO presented with the same orientation, and 11 scenes presented the RO and LO with discordant orientations but with some other degree of contrast. So the comparison between the current results and the previous study concerns very different conditions, and a more sensitive comparison (focusing on the same contrasting orientations) would rely on means calculated only on 3 data points, which are clearly not representative of the entire set of scenes that people saw. In conclusion, the lack of an interaction can be reasonably interpreted as a direct consequence of not using the strongest conflicting cases (as in Burigo & Sacchi, 2013), and not because the orientation of the two objects did not interact.

To be sure that it is converseness that is affecting judgements of spatial language, it is necessary to discount one alternative possible explanation for the effects found for terms on the vertical plane. It could be that the cost in identifying the LO when it is rotated, rather than converseness, affects ratings. All the objects used in this experiment were mono-oriented, and it is well known that naming latencies for familiar mono-oriented objects increase as a function of the angular distance between the orientation of the stimulus and its more familiar upright canonical orientation (Biederman, 2000; Jolicoeur, 1985). Furthermore it is likely that participants rotate these objects to match a familiar orientation automatically (Tarr & Pinker, 1989, 1990). We therefore chose to run a further study using objects without increased identification costs when rotated to test whether identification costs could be discounted as an alternative explanation for the effect.

EXPERIMENT 3

Leek (1998a, 1998b) has shown that poly-oriented objects (such as carrots and pumpkins), unlike mono-oriented objects, do not show reaction time

(RT) differences in recognition time as a function of increasing rotation away from canonical orientation. This is because poly-oriented objects do not have a canonical orientation as they are experienced from multiple views. As these views are presumably stored rather than derived from rotation, they do not require a normalization strategy for their identification. This experiment therefore attempted to replicate the results of the previous experiment using poly-oriented objects. If the effect of the orientation of the LO remained using poly-oriented objects, we could be confident that the effect is due to converseness, and not to identification costs for the LO. It has been also shown that the comprehension of *over/under* is more affected by functional relations between objects than *above/below*, while the comprehension of *above/below* is more affected by geometric relations than *over/under* (cf. Coventry & Garrod, 2004). For that reason, it was of interest to examine also whether converseness affects the comprehension of these terms equally, so, as a secondary goal, we broadened the range of prepositions examined to include *over* and *under* as well as *above* and *below*.

Method

Participants

Twenty-seven students (21 females and 6 males; age range from 19 to 26 years, mean age = 20 years) participated in this study for course credit. All the participants were English native speakers with normal or corrected-to-normal vision.

Design and materials

The experiment again employed an acceptability rating task where participants had to rate the acceptability of sentences containing the spatial prepositions *above, below, over*, and *under* to describe pictures. A pilot study checked that the poly-oriented objects selected from those used by Leek (1998b) from the same categories of fruit and vegetables were indeed not subject to increased identification costs as a function of degree of rotation away from the canonical plane. In order to do this, we presented 10 participants with a word–picture verification task following the methodology used by Leek (1998a). Nouns were presented for 750 ms, followed by a blank screen for 250 ms, followed by a picture for 2500 ms, during which time participants had to make a match/mismatch response. The results confirmed no effect of object rotation on reaction times for true responses ($p > .05$), consistent with the previous results of Leek. In another pilot study we tested eight participants to investigate whether there was consistency regarding the orientation (assignment of top and bottom) of these objects. The results indicate that there was almost perfect agreement in deciding where the head of these poly-oriented objects was, with 95% of subjects providing the same answer. These eight poly-oriented objects were then used as LO and RO but we manipulated the orientation of LO only as we have already shown in Experiment 2 that converseness effects can not be accounted for due to the degree of alignment of the LO and RO. Scenes showing non-oriented axis objects (e.g., barrel, hourglass, tube, etc.; see Appendix for the complete list) as LO were treated as fillers.

Levels of orientation for the LO were: “vertical”, “upside down”, “pointing at” (the RO), and “pointing away” (from the RO). These orientations were selected to be consistent with orientations used in Experiment 2 and with previous experiments that manipulated the orientation of the RO (e.g., Carlson & Logan, 2001; Carlson-Radvansky & Irwin, 1994). As in Experiment 2 in the pointing conditions, the axis of the LO was pointing exactly towards, or away from, the centre of mass of the RO; the distance between LO and RO was manipulated across all the orientations. The LO appeared around the RO in 10 locations (as in Experiment 2): 5 locations above the RO and 5 locations below the RO (see Figure 4). For this experiment, trials where the LO was presented in the locations 3 and 8 and scenes with non-oriented axis objects (128) were treated as fillers for a total of 512 stimuli. The variables in the design were: 2 (preposition sets; above–below vs. over–under) × 2 (superior/inferior prepositions; above–over vs. below–under) × 2 (distance; near vs. far) × 4 (orientations of LO).

Table 3. *Mean acceptability ratings as function of the LO orientation, spatial preposition, and RO–LO distance with poly-oriented objects in Experiment 3*

Spatial Preposition × Distance	*Vertical*	Upside down	*Pointing at*	*Pointing away*
Above				
Far	5.39 (1.93)	5.19 (1.85)	5.05 (1.71)	5.48 (1.75)
Near	6.84 (1.31)	6.72 (1.51)	6.68 (1.65)	7.01 (1.22)
Below				
Far	6.51 (1.53)	6.36 (1.71)	6.72 (1.48)	6.54 (1.64)
Near	5.14 (1.88)	5.12 (1.98)	4.86 (1.91)	4.75 (1.89)
Over				
Far	4.38 (2.02)	3.99 (1.89)	4.1 (1.85)	4.33 (2.02)
Near	6.2 (1.86)	6.13 (1.88)	6.03 (1.94)	6.43 (1.79)
Under				
Far	4.35 (1.89)	4.46 (1.91)	4.19 (2.02)	4.02 (1.77)
Near	6.12 (1.81)	5.86 (1.97)	6.11 (1.89)	6.03 (1.95)

Note: LO = located object; RO = reference object. Standard deviations in parentheses.

Procedure

The procedure was the same as that in Experiment 2.

Results and discussion

The data were treated in the same way as in Experiment 2. Table 3 reports the mean acceptability ratings and standard deviations (collapsed by side) for combinations of LO and RO. The acceptability ratings were submitted to a 2 (superior/inferior preposition; over/above vs. under/below) × 2 (preposition set; over/under vs. above/below) × 2 (distance: near vs. far) × 4 (orientations of the LO) repeated measures ANOVA.

We focus on the effects involving orientation of the LO, as they are informative regarding effects of converseness. The analysis revealed a significant interaction between distance and the orientation of the LO, $F(3, 78) = 3.87$, $MSE = 0.288$, $p < .01$, $\eta_p^2 = .13$, and the three-way interaction between distance, orientation of the LO, and superior/inferior prepositions was also significant, $F(3, 78) = 3.75$, $MSE = 0.29$, $p < .015$, $\eta_p^2 = .126$. This interaction is displayed in Figure 6. Post hoc analyses revealed that for superior prepositions in far positions, "vertical" ($M = 4.88$) and "pointing away" ($M = 4.9$) orientations—orientations where converseness holds—were rated higher than "upside down" ($M = 4.58$) and "pointing at" ($M = 4.57$) orientations ($p < .01$)—orientations where converseness does not hold. For inferior prepositions in far locations, "vertical" ($M = 4.74$) and "upside down" orientations ($M = 4.78$) were rated higher than "pointing at" ($M = 4.52$) and "pointing away" ($M = 4.38$) orientations ($p < .01$), again consistent with when converseness does versus does not hold.

For near locations the results were also consistent with the presence or absence of converseness. For superior prepositions in near locations, scenes where the LO was "pointing away" from the RO were rated higher ($M = 6.72$) than "upside down" ($M = 6.42$) and "pointing at" ($M = 6.34$) scenes ($p < .01$). Finally, for inferior prepositions in near locations, scenes where the LO was pointing at the RO received higher ratings ($M = 6.41$) than "upside down" orientations ($M = 6.12$) ($p < .01$). No other pair-wise differences were found, suggesting that the interaction between distance and the orientation of the LO only reflected the overall preference for trials with the LO placed near the RO. This is in line with previous studies showing that scenes where the LO was placed closer to the RO received higher ratings than scenes where the LO was placed farther away from the RO (Carlson-Radvansky & Logan, 1997; Hayward & Tarr, 1995). In addition, since

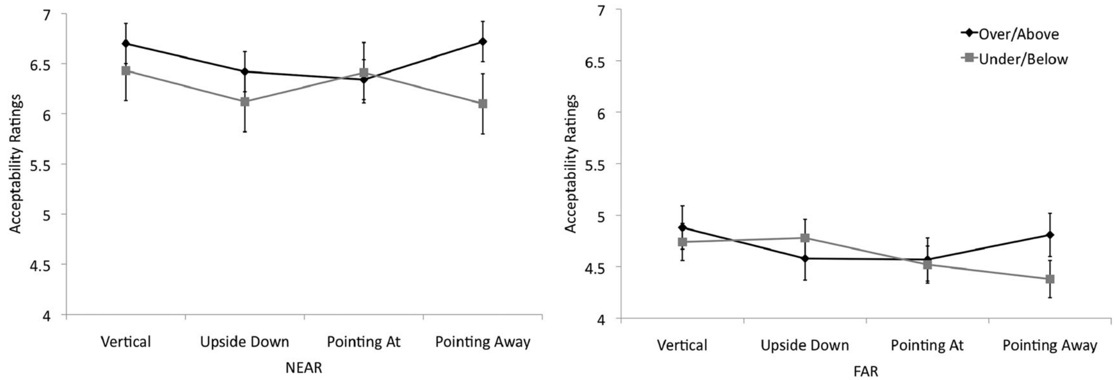

Figure 6. *Interaction between proximity, orientation of the located object (LO), and superior/inferior prepositions in Experiment 3. Error bars represent 95% confidence intervals for within-participant data (see Loftus & Masson, 1994; Masson & Loftus, 2003).*

the distribution of the acceptability ratings for near and far are consistent (with the exception for the "pointing at" orientation at far distance for inferior prepositions), the results suggest that the effects of the orientation of the LO described here take place regardless of the distance between the objects.

The ANOVA also revealed significant main effects of distance, $F(1, 26) = 80.01$, $MSE = 7.98$, $p < .0001$, $\eta_p^2 = .755$, of superior/inferior spatial prepositions, $F(1, 26) = 8.46$, $MSE = 0.762$, $p < .007$, $\eta_p^2 = .246$, and of preposition set, $F(1, 26) = 13.19$, $MSE = 8.59$, $p < .001$, $\eta_p^2 = .337$, together with significant interactions between distance and preposition set, $F(1, 26) = 13.83$, $MSE = 0.449$, $p < .001$, $\eta_p^2 = .347$, and between superior/inferior prepositions and preposition set, $F(1, 26) = 4.33$, $MSE = 0.734$, $p < .047$, $\eta_p^2 = .143$. These interactions revealed an overall preference for *above/below* compared to *over/under* prepositions and support the observation that these two sets of prepositions have different spatial templates (Coventry et al., 2001, but see Regier & Carlson, 2001, for a different claim). None of the other main effects or interactions were significant.

In summary, the current experiment replicates the effect of converseness found in the previous experiment using poly-oriented objects rather than mono-oriented objects. Such objects are not associated with increased identification costs, and therefore the fact that the orientation of LO still affects comprehension for these objects allows us to discount normalization costs as an explanation for the effect.

GENERAL DISCUSSION

Across four sets of spatial relations covering both vertical and horizontal axis, we demonstrated that the presence or absence of a converseness relation in spatial scenes affects the acceptability of scene descriptions. These findings replicated the effects of the orientation of the located object observed previously by Burigo and Sacchi (2013). This is particularly important according to the growing literature emphasizing the relevance of replications (Cumming, 2013). Furthermore, these results extend previous studies corroborating the idea that geometric properties of the located object are important and contradicting the cognitive linguistics idea that the located object is irrelevant for spatial language comprehension (Jackendoff, 1983; Talmy, 1983; but see Valentine, 2001, for some evidence in contrast with this view). Moreover, this study not only provides support for the relevance of the orientation of the LO, but also shows for the first time that the orientation of the LO is important as a function of the inferences people are able to make—converseness—during spatial language comprehension. The degree to which X can be said to be *above* Y or *in* *front of* Y is dependent on the degree to which Y can be said to be *below* X or *behind* X. When converseness between two objects did not hold, the acceptability for the spatial term used to describe their relation received lower ratings than the same spatial term used for a scene where converseness did hold.

In Experiment 1 we tested whether flouting of converseness through manipulation of the orientation of the LO affects the appropriateness of a spatial expression involving *in front of/behind* to describe the position of an LO in relation to an RO. The outcomes established that the orientation of the LO does affect the appropriateness of a spatial expression containing horizontal spatial prepositions to describe simple scenes containing two objects. Specifically, when the orientation of the LO was such that the property of converseness could not hold, the appropriateness was lower than for scenes where the orientation of the LO allowed the converseness property.

According to the observation that converseness could be violated only in respect to an intrinsic reference frame, in Experiment 2 we manipulated the orientations of both LO and RO in order to test the possibility that the comprehension of *above* and *below* is affected by the extent to which converseness applies regardless of which reference frames have been selected. The results indicate that the orientation of the LO is important regardless of which reference frame is active, and also that converseness is taken into account even when there is cost associated with the processing of reference frames for the RO.

Experiment 3 set out to test whether converseness affected judgements of a range of prepositions on the vertical axis while eliminating other possible reasons why rotation of the LO might impact upon language ratings for these terms. The data from this experiment allowed us to discount an alternative explanation for the effect—cost in identifying the LO. The effect of the orientation of LO persisted even when the LOs used were poly-oriented objects and therefore do not have increased cost associated with their identification as a function of increasing rotation away from the canonical orientation. Experiment 3 tested also whether converseness is important for the comprehension of *over/under* in addition to *above/below*; the results of this experiment provide support for the general importance of converseness across a range of spatial relations and prepositions while discounting alternative explanations for the effect.

Now if one subscribes to the view that spatial language serves the function of narrowing the search for an object by locating the object in relation to a second known object (e.g., Landau & Jackendoff, 1993; Regier & Carlson, 2001; Talmy, 1983), then one can ask why participants consider converseness at all when this entails additional work in spatial language comprehension that at first sight might appear superfluous. From the point of view of more recent accounts attributing a greater role to the inferential mechanism (Coventry & Garrod, 2004; Tyler & Evans, 2003), where spatial language is taken to communicate information about the most informative spatial relations present in the scene being described, consideration of converseness is not unnecessary work, but affects just how informative a given spatial expression is. This idea is in line with a pragmatic approach to language processing. Talking about the spatial world informs the hearer about the state of the world at the immediate time of the utterance, but also about sets of inferences that should follow from the given spatial expression in line with the duty that speakers have to avoid statements that are informationally weaker than their knowledge of the world allows (Asher & Lascarides, 2003; Levinson, 2000). Describing the position of X in a scene with reference to Y carries with it the assumption that the position of Y is important also. Hence one can argue that it is not by chance that languages such as English cluster many lexical items into pairs so that language can reflect the multiple relations that hold between objects. As a consequence, people are sensitive to the logical properties of language when they comprehend it and test out whether converseness holds in order to assess the felicitousness of a given spatial expression.

However, computing the acceptability of a spatial description and/or establishing whether converseness holds are two distinct processes.

Inferring whether converseness applies to a given description depends only on whether the rule—A is *above* B then B is *below* A—applies. The acceptability, on the other hand, reflects the spatial template that people have built on the reference object. For this reason, acceptability presents some granularity while the logic of converseness does not.

While the present experiments indicate that people consider converseness when judging how well spatial expressions describe pictures involving pairs of objects, the results do not speak to the issue of the time course of consideration of converseness during processing of spatial language, nor do the results indicate that converseness is considered obligatorily. Further studies using more on-line methods are required to address these issues. Nevertheless, the results have potential implications for computational models of spatial language. Currently models of spatial language assume that direction is assigned from the RO to the LO after multiple reference frame activation, and that attention is directed from the RO to the LO in order to establish the goodness of fit between a given spatial preposition and a given visual scene (e.g., Regier & Carlson, 2001). The present research suggests that attention is distributed across both objects in the scene (consistent with Lavie, 1995, 1997) and that there is an active search for alternative spatial relations to describe those objects where attention must be allocated from the LO, as denoted in the sentence, to the RO. Recent eye tracking experiments have indeed shown that visual attention is flexibly allocated across the objects (Coventry et al., 2010) and that attentional shifts from the LO to the RO occur when participants are judging whether a given spatial expression correctly describes that scene (Burigo & Knoeferle, 2015). However, it remains to be established exactly how and when attention allocation is affected by the absence of converseness in a spatial scene.

REFERENCES

Asher, N., & Lascarides, A. (2003). *Logics of conversation*. Cambridge: Cambridge University Press.

Biederman, I. (2000). Recognizing depth-rotated objects: A review of recent research and theory. *Spatial Vision*, *13*(2–3), 241–253.

Brown, P. (1994). The INs and ONs of tzeltal locative expressions: The semantics of static descriptions of location. *Linguistics*, *32*, 743–790.

Burigo, M., & Knoeferle, P. (2015). Visual attention during spatial language comprehension. *PLoS ONE*, *10*(1): e0115758, 1–21. doi:10.1371/journal.pone.0115758

Burigo, M. & Sacchi, S. (2013). Object orientation affects spatial language comprehension. *Cognitive Science*, *37*, 1471–1492.

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

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

Carlson, L. A. & Van Deman, S. R. (2008). Inhibition within a reference frame during the interpretation of spatial language. *Cognition*, *106*(1), 384–407.

Carlson-Radvansky, L. A., & Irwin, D. E. (1993). Frame of reference in vision and language: where is above? *Cognition*, *46*(3), 223–244.

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

Carlson-Radvansky, L. A., & Jiang, Y. (1998). Inhibition accompanies reference frame selection. *Psychological Science*, *9*(5), 386–391.

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

Carlson-Radvansky, L. A. & Radvansky, G. A. (1996). The influence of functional relations on spatial term selection. *Psychological Science*, *7*, 56–60.

Carlson-Radvansky, L. A., & Tang, Z. (2000). Functional influences on orientering a reference frame. *Memory and Cognition*, *28*(5), 812–820.

Coventry, K. R., Christophel, T., Fehr, T., Valdés-Conroy, B., & Herrmann, M. (2013). Multiple routes to mental animation: language and functional relations drive motion processing for static images. *Psychological Science*, *24*(8), 1379–1388.

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

Coventry, K. R., Lynott, D., Cangelosi, A., Monrouxe, L., Joyce, D., & Richardson, D. C. (2010). Spatial language, visual attention, and perceptual simulation. *Brain and Language*, *112*(3), 202–213.

Coventry, K. R., Prat-Sala, M., & Richards, L. (2001). The interplay between geometry and function in the comprehension of over, under, above and below. *Journal of Memory and Language*, *44*(3), 376–398.

Cumming, G. (2013). The New statistics. Why and how. *Psychological Science*, *25*(1), 7–29.

Feist, M. I. (2000). On in and on: An investigation into the linguistic encoding of spatial scenes. (Doctoral dissertation). Retrieved from the Language Description Heritage online library of the Max Planck Society http://ldh.livingsources.org/2000/01/01/escidoc406832/.

Feist, M. I., & Gentner, D. (2012). Multiple influences on the use of English spatial prepositions: The case of "in" and "on". In C. Boonthum-Denecke, P. M. McCarthy, & T. Lamkin (Eds.), *Cross-disciplinary advances in applied natural language processing: issues and approaches* (pp. 305–323). Hershey, PA: IGI Global.

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

Jackendoff, R. (1983). *Semantic and cognition*. Cambridge, MA: MIT Press.

Jolicoeur, P. (1985). The time to name disoriented natural objects. *Memory and Cognition*, *13*(4), 289–303.

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

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

Lavie, N. (1997). Feature integration and selective attention; response competition from unattended distractor features. *Perception and Psychophysics*, *59*, 543–556.

Leek, E. (1998a). The analysis of orientation-dependent time costs in visual recognition. *Perception*, *27*(7), 803–816.

Leek, E. (1998b). Effects of stimulus orientation on the recognition of common polyoriented objects. *Psychonomic Bulletin and Review*, *5*, 650–658.

Levelt, W. J. M. (1984). Some perceptual limitation on talking about space. In A. J. van Doorn, W. A. van der Grind, & J. J. Koenderik (Eds.), *Limits on perception* (pp. 323–358). Utrecht: VNU Science Press.

Levelt, W. J. M. (1996). Perspective taking and ellipsis in spatial description. In P. Bloom, M. A. Peterson, L. Nadel, & M. F. Garret. (Eds.), *Language and space* (pp. 78–107). Cambridge, MA: MIT press.

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

Levinson, S. C. (1996b). Language and space. *Annual Review of Anthropology*, *25*, 353–382.

Levinson, S. C. (1996c). Relativity in spatial conception and description. In J. Gumperz & S. C. Levinson (Eds.), *Rethinking linguistic relativity* (pp. 177–202). Cambridge, UK: Cambridge University Press.

Levinson, S. C. (2000). *Presumptive meanings: The theory of generalized conversational implicature*. Cambridge, MA: The MIT Press.

Loftus, G. R., & Masson, M. E. J. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin & Review*, *1*, 476–490.

Masson, M. E. J., & Loftus, G. R. (2003). Using confidence intervals for graphically based data interpretation. *Canadian Journal of Experimental Psychology*, *57*(3), 203–220.

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

Talmy, L. (1983). How language structures space. In H. Pick, & L. Acredolo (Eds.), *Spatial orientation: theory, research and application* (pp. 225–282). New York: Plenum Press.

Tarr, M., & Pinker, S. (1989). Mental rotation and orientation-dependence in shape recognition. *Cognitive Psychology*, *21*(2), 233–282.

Tarr, M., & Pinker, S. (1990). When does human object recognition use a viewer-centered reference frame? *Psychological Science*, *1*(4), 253–256.

Taylor, H. A., & Rapp, D. N. (2004). Where is the donut? factors influencing spatial reference frame use. *Cognitive Processing*, *5*(3), 175–188.

Tyler, A., & Evans, V. (2003). *The semantic of English preposition. spatial scenes, embodied meaning and cognition*. Cambridge: Cambridge University Press.

Valentine, R. (2001). *Nishnaabemwin reference grammar*. Toronto: University of Toronto Press.

APPENDIX

Complete lists of objects presented

List of objects employed in Experiment 1 as the located object (LO) and the reference object (RO)

- bear, dog, elephant, frog, horse, man, penguin, pigeon

List of objects employed in Experiment 2 as LO

- *Oriented axis objects*: box, cat, chicken, hat, monkey, pan, squirrel, vase
- *Non-oriented axis objects*: barrel, drum, hourglass, ladder, pen (with two writing ends), stick, tube, wand.
- *No axis objects*: cogwheel, fan, football, porthole, rock, shield, ship's wheel, wheel.

List of objects employed in Experiment 2 as RO

- *Oriented axis objects*: box, cat, chicken, hat, monkey, pan, squirrel, vase

List of objects employed in Experiment 3 as LO and RO

- *Poly-oriented objects*: pumpkin, apple, carrot, courgette, peach, pepper, pineapple, strawberry.

List of objects employed in Experiment 3 as LO

- *Non-oriented axis objects*: barrel, drum, hourglass, ladder, pen (with two writing ends), stick, tube, wand.