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The Influence of Reference Frame Selection on Spatial Template Construction

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The use of spatial relational terms requires the selection of a reference frame and the construction of a spatial template. The reference frame divides up space, indicating above/below, front/back, and left/right directions. Spatial templates are applied to reference frames and define regions in space that correspond to good, acceptable, and bad uses of particular spatial relations. In two experiments we examined whether reference frame selection influences the spatial templates that are constructed for the spatial relations ‘‘above’’ and ‘‘below.’’ Results indicated two such influences, one operating across trials and one operating within a trial. Across trials, the preferences for using the different types of reference frames directly influenced the parsing of space, such that when multiple spatial templates were constructed, they were combined to form a composite template. Spatial templates constructed for the different reference frames were very similar, indicating that the type of reference frame did not alter the overall shape or relative sizes of the regions within the spatial template. Within a trial, the activation of multiple reference frames during reference frame selection resulted in the construction of multiple spatial templates, even when instructions were given to respond on the basis of a single reference frame.

Everyday tasks often require spatially relating one object with respect to a second object, such as positioning the remote control in front of the television set when turning the channels. Such situations can be described in English using spatial relational terms, as in ‘‘The remote control is in front of the television.’’ Work in both psychology and linguistics has focused on how such spatial relations are computed and described (e.g., Carlson-Radvansky & Irwin, 1994; Hayward & Tarr, 1994; Herskovits, 1986; Jackendoff & Landau, 1991; Levelt, 1984; Logan & Sadler, 1996; Miller & Johnson-Laird, 1976; Talmy, 1983).

Central to the use of spatial relations is the selection of a *reference frame*, a set of three orthogonal coordinate axes whose intersection point is the origin (e.g., Miller & Johnson-Laird, 1976). Reference frames have a scale that defines units of distance, an orientation that is assigned to each axis that specifies whether it refers to the above/below, front/back, or left/right dimension, and a direction that defines the endpoint of each axis (e.g., which endpoint is left and which is right for the left/right axis). These parameters are not

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fixed (Logan & Sadler, 1996; Morrow & Clark, 1988). For example, the axes of a reference frame may be rotated in space about the origin, in accordance with various sources of information. This results in three distinct classes of reference frames (Farah, Brunn, Wong, Wallace, & Carpenter, 1990; Friederici & Levelt, 1990; Garnham, 1989; Hinton & Parsons, 1988; Miller & Johnson-Laird, 1976). The *viewer-centered reference frame* uses the orientation of the viewer of the scene to define the axes, such that one axis is aligned with the viewer's head and feet, and the other axes are aligned with the viewer's front and back and left and right sides. The *object-centered reference frame* uses the predefined intrinsic sides of an object (i.e., top, bottom, front, back, left, and right) to orient the axes. The *environment-centered reference frame* uses salient properties of the environment to orient its axes, such as gravity for the vertical axis, or the sides of a room for the horizontal axes.[1]

Also of central importance to the use of spatial relations is the assignment of roles to each of the objects involved (e.g., Herskovits, 1986; Jackendoff & Landau, 1991; Levelt, 1984; Logan, 1995; Logan & Sadler, 1996; Miller & Johnson-Laird, 1976; Talmy, 1983). The *located object* is the object whose location is being described, and the *reference object* is the object in relation to which the position of the located object is defined. In the example above, the television is the reference object and the remote control is the located object.

According to many theories of the use of spatial relations (e.g., Carlson-Radvansky & Irwin, 1994; Garnham, 1989; Herskovits, 1986; Jackendoff & Landau, 1991; Levelt, 1984; Logan & Sadler, 1996), finding the located object involves the following basic steps: (a) identifying the reference object; (b) superimposing the origin of a reference frame on the reference object; (c) orienting the axes with respect to the defining source of information; (d) identifying the direction assigned to the spatial relation by the relevant axis of the reference frame; and (e) verifying that the located object is present in a relevant location. For example, to locate the remote control, one could superimpose an object-centered reference frame on the television, orient its axes on the basis of the television's predefined sides, identify the ''front'' end of the ''front/back'' horizontal axis, and then verify whether an encountered object in that direction was the remote control.

Two important steps are missing from this sequence. First, given that there are different types of reference frames, how is one selected to assign a direction to the spatial term? We refer to this process as *reference frame selection.* Second, is search for the located object restricted to the axis of the reference frame that specifies the relevant direction or is the area surrounding the axis also explored? Recent evidence suggests that regions of space that correspond to good, acceptable, and bad uses of various spatial relations can be mapped out (Logan & Sadler, 1996; see also Hayward & Tarr, 1995; Franklin, Henkel, & Zengas, 1995). We refer to this process as *spatial template construction* (Logan & Sadler, 1996). The goal of this paper is to examine the influence of reference frame selection on the construction of spatial templates. Accordingly, each process is addressed further below, focusing on the vertical spatial terms ''above'' and ''below.'' Implications for other spatial relations will be discussed under General Discussion.

[1] Levinson (1996) has proposed a new framework for classifying reference frames as intrinsic, absolute, and relative. Generally, as defined here, the viewer-centered reference frame maps onto the relative frame, the environment-centered reference frame maps onto the absolute frame, and the object-centered reference frame maps onto intrinsic frame. In addition, it should be noted that the viewer-centered reference frame and the environment-centered reference frames really represent families of reference frames that are coincident in these experiments and therefore cannot be distinguished. For example, the viewer-centered reference frame may be body-based, head-based, or retina-based. The environment-centered reference frame may be based on gravity, on the lab room, or on the computer screen.

REFERENCE FRAME SELECTION

Sometimes the vertical axes of different reference frames are dissociated, such as when the viewer is reclining or when the reference object is rotated from the upright (such as a glass lying on its side). In these cases, the directions assigned to ''above'' and ''below'' differ across the types of reference frames. Given such conflict, one needs to determine not only which reference frame is ultimately selected for spatial term assignment (Carlson-Radvansky & Irwin, 1993) but also how the selection is made (Carlson-Radvansky & Irwin, 1994). These two issues focus on difference aspects of reference frame selection: (1) a documentation of the preferences for and consistency of using particular reference frames across trials and (2) an explanation of the processes involved in the actual selection of a reference frame within a trial. The influence of the first aspect on spatial template construction was examined in Experiment 1. The influence of the second aspect was examined in Experiment 2, so discussion of it is postponed until then.

PREFERENCES FOR REFERENCE FRAMES

A number of factors have been identified that influence the preferences for using particular reference frames, such as the functional relation between the located and reference objects (Carlson-Radvansky & Radvansky, 1996); characteristics of the objects in the scene, such as movement (Fillmore, 1975; Levelt, 1982); the communicative purpose of the task (Plumert, Carswell, DeVet, & Ihrig, 1995); the need to coordinate between the listener and the speaker (e.g., Clark & Wilkes-Gibbs, 1986; Schober, 1993), and the perspective adopted on the scene (e.g., Bryant, Tversky, & Franklin, 1992). When such factors are held constant, baseline preferences can be observed. For example, Carlson-Radvansky and Irwin (1993) examined which reference frames were preferred to assign directions to vertical spatial relations under conditions in which all of the reference frames were dissociated. The results suggested an ordered preference, with greatest use of the environment-centered reference frame, followed by smaller but significant use of the object-centered reference frame, and no significant use of the viewer-centered frame (see also Friederici & Levelt, 1990). However, these preferences did not generally reflect the exclusive acceptance of one type of reference frame by all subjects. That is, some subjects showed a mixed use of reference frames, such that they switched between competing assignments of the same spatial relation across trials.

SPATIAL TEMPLATES

Recent research (Logan & Sadler, 1996; see also Franklin et al., 1995; Gapp, 1994; Hayward & Tarr, 1995) has focused on the construction of spatial templates as a reflection of how spatial relations parse up space. For example, Logan and Sadler presented subjects with a central reference object (an ''O'') that was located in the middle of an invisible 7 $\times$ 7 grid (in cell 4,4). Across trials, they placed the located object (an ''X'') in each of the remaining cells in the grid and asked subjects to rate the acceptability of 10 spatial terms as descriptions of the relation between the X and the O (see also Hayward & Tarr, 1995). The acceptability ratings were then combined across trials to construct a spatial template, like the one for ''above'' that is shown in Fig. 1 (data from Logan & Sadler, Experiment 2). On this three-dimensional plot, the *x*-axis represents rows and the *y*-axis represents columns of the 7 $\times$ 7 grid. The *z*-axis represents the mean acceptability rating for each location within the grid.

Although the ratings across the templates were continuous, Logan and Sadler (1996) found it useful to distinguish regions that seemed to represent good or prototypical (Hayward & Tarr, 1995) uses of the spatial relation, acceptable uses, and unacceptable or bad uses. These regions are indicated on the figure and are defined explicitly later. Generally, good regions received the highest ratings,

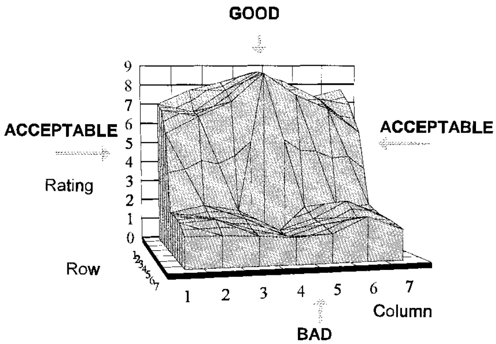

FIG. 1. Spatial template for the spatial relation ''above'' constructed from Experiment 2 of Logan and Sadler (1996). The *x*-axis represents the rows of the grid, the *y*-axis represents the columns, and the *z*-axis represents the mean acceptability rating for the located object at each position within the grid. The reference object was in cell (4,4).

and distance away from the reference object did not influence judgments (see also Logan & Compton, 1996). Acceptable regions received intermediate ratings and were symmetric about the good region, although the distinction between these regions was gradual, with ratings dropping as a function of distance (see also Hayward and Tarr, 1995). Bad regions corresponded to very low acceptability ratings and were sharply distinct from the acceptable and good regions.

Note that spatial templates are not just elaborations of reference frames, with regions of acceptability defined for each endpoint (above, below, front, back, left, right). Rather, templates should be viewed as distinct from reference frames. The primary reason for this is the relatively large number of spatial relations that would have to be instantiated by a reference frame. Indeed, Landau and Jackendoff (1993) note that between 80 and 100 spatial relations are lexicalized (as prepositions) in English. The number of different relations that people can actually apprehend may be even larger. If spatial templates were parts of reference frames, then the selection of a reference frame would result in the simultaneous availability of more than 80 spatial templates, which seems excessive. Our view is that spatial templates are separate from reference frames, in that they are constructed and applied in response to the activation of a reference frame in the context of a particular spatial relation.

EXPERIMENT 1

Experiment 1 was designed to uncover the preferences for and consistency of using particular reference frames and spatial templates across trials. Note that this could not be done in the experiments by Logan and Sadler (1996; see also Hayward & Tarr, 1995), because the reference frames were always aligned and assigned the same directions to the spatial relations. Therefore, whether subjects were using one reference frame consistently or switching back and forth could not be determined. To illustrate, a schematic template corresponding to the spatial relation ''above'' with an upright reference object is shown in Fig. 2a. The letters G, A, and B designate the good, acceptable, and bad regions, respectively, as defined by Logan and Sadler. Assuming an upright viewer, all reference frames would align the spatial template in this manner. Therefore, for Experiment 1 we modified the procedure to include trials in which the reference frames were not coincident. Specifically, sometimes the reference object was upright (canonical trials) and sometimes it was rotated, thereby dissociating the object-centered reference frame from the viewer-centered and environment-centered reference frames (noncanonical trials).

For noncanonical trials, we reasoned that if subjects consistently use the same reference frame on each trial, then the spatial template constructed across trials would directly correspond to the spatial template used on any given trial. Figure 2b illustrates a spatial template emerging from the exclusive use of the viewer/environment-centered[2] reference frame to assign

[2] In these experiments, the viewer-centered frame was always aligned with the environment-centered reference frame (e.g., subjects were upright); therefore, we will refer to this combination as the viewer/environment-centered reference frame. However, it should be noted that Carlson-Radvansky and Irwin (1993; 1994) demonstrated lit-

above (henceforth, a viewer/environment template); and Figure 2c illustrates a spatial template emerging from the exclusive use of the object-centered reference frame to assign above (henceforth, an object template).

In contrast, if subjects used a mixture of reference frames across trials (Carlson-Radvansky & Irwin, 1993), then the spatial template emerging across trials may reflect a combination of the viewer/environment template, as used on some trials, and the object template, as used on other trials. This is illustrated in Fig. 2d, which reflects an equally weighted mixture of similarly shaped viewer/environment templates (as in Fig. 2b) and object templates (as in Fig. 2c). The subscript letters VE and O refer to the viewer/environment and object templates, respectively. It should be clear that the resulting spatial template in Fig. 2d is very different from the templates based exclusively on one reference frame (as in Figs. 2b and 2c) in terms of its overall shape and its regions. For example, the nine cells in the top left quadrant in Fig. 2d combine acceptable ratings from both the viewer/environment template and the object template; this will be referred to as the *VEO acceptable region.* Therefore, across these nine cells, an average based on intermediate ratings from either template would be expected. In contrast, the nine cells in the bottom left and the nine cells in the top right quadrants combine acceptable ratings from one template and bad ratings from a second template. These regions are named for the reference frame that defines them as acceptable and will be referred to as the *O acceptable region* and the *VE acceptable region,* respectively. Therefore, across the nine cells in each quadrant, an average based on intermediate and low ratings would be expected. Consequently, if subjects use a mixture of spatial templates, then the VEO acceptable region should receive higher acceptability ratings than for either the VE acceptable region or the O acceptable region.

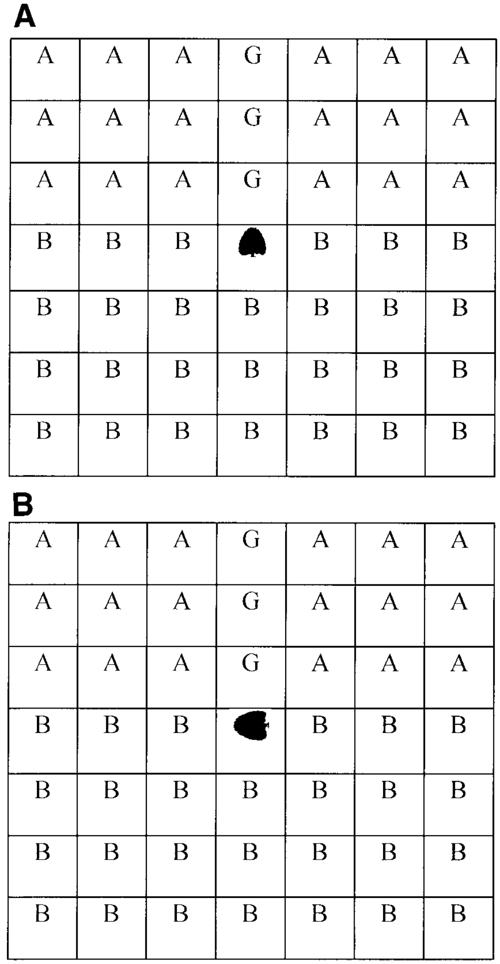

FIG. 2. Schematic spatial templates for the spatial relation "above." (A) Spatial template constructed for a canonical reference object on the basis of coincident viewer/environment-centered and object-centered reference frames. (B) Spatial template constructed for a noncanonical reference object on the basis of only the viewer/environment-centered reference frame. (C) Spatial template constructed for a noncanonical reference object on the basis of only the object-centered reference frame. (D) Spatial template for the spatial relation "above" constructed for a noncanonical reference object on the basis of a combined viewer/environment template (as in B) and an object template (as in C). G refers to a good region, A refers to an acceptable region, B refers to a bad region, subscript VE refers to the viewer/environment template, and subscript O refers to the object template.

tle to no use of the viewer-centered reference frame in making assignments to vertical spatial terms such as "above" and "below"; therefore, we believe that within this combination, the environment-centered reference frame is carrying the activation and is involved in constructing the spatial template. Of course, it is entirely possible that for other spatial terms (e.g., front and back) the viewer-centered reference frame is very active and perhaps even dominates the other reference frames.

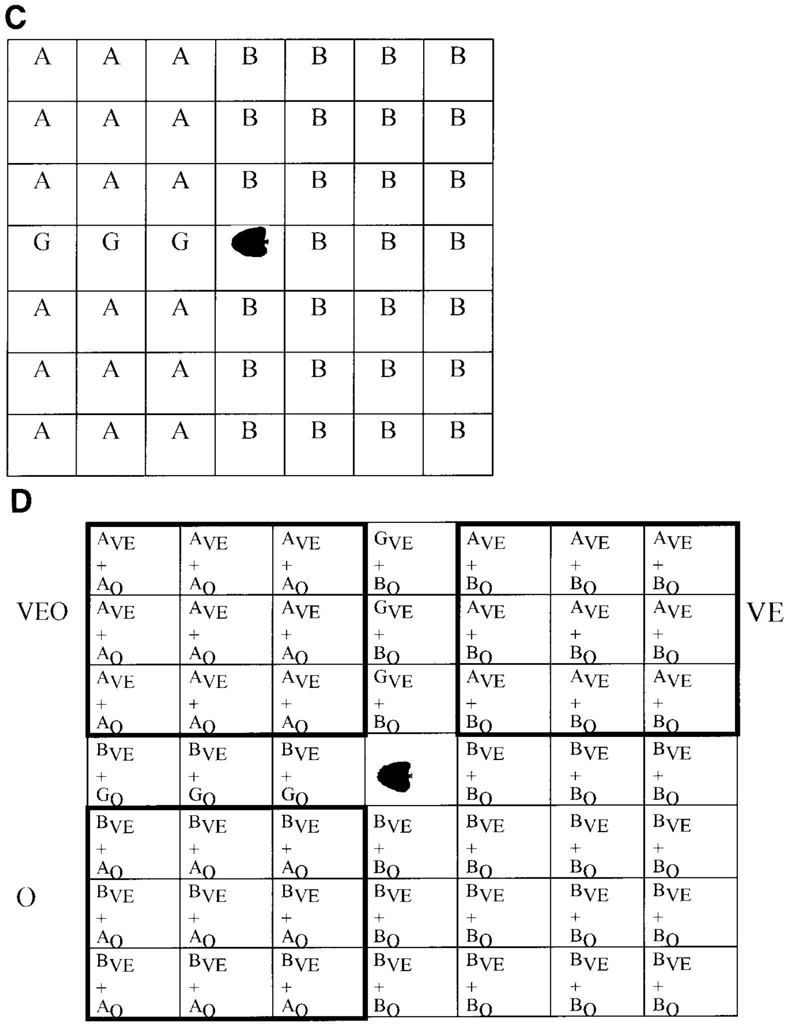

FIG. 2—*Continued*

However, if subjects use only a single reference frame exclusively, then no such differences are expected amid the corresponding regions in the spatial templates in Figs. 2b and 2c. For Fig. 2b, the ratings for the top left and top right quadrants (both acceptable regions) should be intermediate and roughly equal, whereas the ratings for the bottom left quadrant (a bad region) should be uniformly low; for Fig. 2c, the ratings for the top left and bottom left quadrants should be intermediate (both acceptable regions) and roughly equal, whereas the ratings for the top right quadrant (a bad region) should be uniformly low.

Method

Subjects

Twenty-two University of Notre Dame undergraduates participated in exchange for partial credit in an introductory psychology class.

Stimuli

The picture displays contained a central reference object placed on a white square field that measured 14 cm along a side. The central object was a colored image of a tree, adapted from the CorelDraw! 4.0 ‘‘tree.cdr’’ picture. The tree measured 3.2 cm vertically and 2.5 cm horizontally. The reference object was always placed in the center of a 7 × 7 grid (row 4, column 4); each cell in the grid measured 2 × 2 cm. On half of the displays, the reference object appeared upright in a canonical orientation; on the other half, it appeared rotated 90° into a noncanonical orientation. For 12 subjects, the rotation was clockwise, with the top of the tree pointing to the right edge of the display; for 10 subjects, the rotation was counter-clockwise, with the top of the tree pointing to the left edge. The picture displays also contained a located object which was a 3-mm green square. Throughout the experiment, the square was placed in each of the 48 unoccupied cells four times, once for each spatial term (see below).

Each picture display was preceded by a sentence of the form ‘‘The square is _________ the tree,’’ which was presented for 2 s. The blank was filled in with the spatial relation ‘‘above,’’ ‘‘below,’’ ‘‘to the left of,’’ or ‘‘to the right of.’’ The sentence was presented in light blue on a black screen using a default 8 × 8 bit-mapped font. To encourage subjects to look at the center of the screen where the central reference object would appear, the spatial relations were centered in the display and were capitalized.

Design

There were 384 trials, constructed from the following variables: 2 orientations (canonical and noncanonical) × 4 spatial terms (above, below, left and right) × 48 locations. The trials were presented in a different random order to each subject.

Procedure

Subjects were instructed that they would be shown sentence–pictures pairs and would be asked to rate the acceptability of the sentence as a description of the picture using a 10-point scale, with 0 denoting not at all acceptable; 5, moderately acceptable; and 9, perfectly acceptable. They were told to base their responses on whether they thought the spatial term was acceptable in any manner. There was an initial set of five practice trials to familiarize subjects with the task. Trials were self-paced, and the experiment lasted about 30–45 min.

Results and Discussion

Mean acceptability ratings broken down by orientation of the reference object (canonical and noncanonical) and spatial relation (above and below) were calculated across subjects for each position of the located object. Acceptability ratings for trials with sentences containing the ‘‘left of’’ and ‘‘right of’’ relations were analyzed, and showed generally the same pattern as the ratings for ‘‘above’’ and ‘‘below.’’ These analyses are not presented because a tree does not have an intrinsic front, back, left, or right side, thus making use of an object-centered frame hard to interpret.[3] Unless otherwise noted, a *p*-level of .05 was adopted for significance. For both experiments, follow-up tests were based on critical differences required for significance that were calculated on the basis of 95% confidence intervals using the error term from the interaction or main effect of the appropriate analysis of variance (Fisher, 1966; Loftus & Masson, 1994).

[3] One could argue that a reference frame can easily be imposed on a tree, such that there would be little to no ambiguity in complying with a request such as, ‘‘Put the ball to the left of the tree.’’ However, such an imposed reference frame would presumably use the viewer as the basis for axis orientation, not an object-centered frame. This makes our analyses difficult to interpret because subjects were using both a ‘‘real’’ viewer-centered reference frame aligned with their bodies and the environment and a ‘‘virtual’’ viewer-centered reference frame that is rotated 90° out of alignment. Exactly how this ‘‘virtual’’ viewer-centered reference frame interacts with the ‘‘real’’ viewer-centered reference frame and the environment-centered reference frame is a very interesting question for further study. However, for the sake of space, we do not address these data further here.

TABLE 1

MEAN ACCEPTABILITY RATINGS FOR ABOVE AND BELOW BY POSITION IN 7 × 7 GRID FOR CANONICAL TRIALS (TOP) AND NONCANONICAL TRIALS (BOTTOM)

	Spatial relation													
	Above							Below						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7
	Canonical trials													
R1	7.3	7.8	8.1	9.0	7.9	7.4	6.7	0	.3	0	.1	.4	.7	0
R2	6.6	7.2	7.4	8.8	7.4	7.1	6.7	0	.1	.8	.6	.1	.5	.1
R3	5.7	5.7	6.5	9.0	6.5	5.8	4.8	.2	.5	0	.2	.4	0	0
R4	.3	1.0	.6	–	.8	.2	0.5	.2	.4	.1	–	.5	.2	.3
R5	.3	0	0	.1	.3	.2	0.1	3.7	5.7	5.6	8.6	6.5	5.2	4.2
R6	0	.8	0	0	0	0	0.1	6.0	6.6	7.7	8.5	6.5	6.6	6.5
R7	0	0	0	.4	0	0	0	6.9	6.5	7.0	8.6	6.7	7.4	6.3
	Noncanonical trials													
R1	7.0	6.7	5.5	3.0	3.3	3.9	3.3	0	.5	0	.8	3.2	2.9	3.0
R2	7.0	6.0	5.6	4.2	2.9	3.2	2.5	0	.1	0	.3	2.9	3.1	3.4
R3	6.2	6.9	6.2	4.1	2.6	3.0	2.7	.1	.1	.5	0	4.0	4.4	5.3
R4	5.9	6.4	6.1	–	.2	.2	.2	0	.6	.6	–	6.1	5.8	6.0
R5	4.7	5.1	3.9	0	.1	0	.1	2.0	1.5	3.2	3.5	5.4	4.8	6.1
R6	4.6	4.4	3.7	.4	.4	.1	0	2.9	3.7	3.6	3.4	5.5	5.9	6.1
R7	4.3	4.1	2.5	.1	.5	.1	0	3.3	3.1	4.2	3.0	4.6	5.2	5.7

Note. For all grids, the reference object was located in cell (4, 4). For noncanonical trials, the reference object was rotated 90° counter-clockwise in the picture plane. R, row; C, column.

Spatial Templates across Trials

Canonical trials. The mean acceptability ratings for each position for each spatial relation are presented in Table 1. For these and all subsequent spatial templates, we divided the spatial templates into good, acceptable, and bad regions on the basis of the designations made by Logan and Sadler (1996); these classifications were thus independent of our own subjects' ratings. Specifically, we defined good regions as those cells that ran along the vertical axes of the coincident viewer/environment-centered and object-centered reference frames (e.g., column 4 in rows 1–3 for above and column 4 in rows 5–7 for below). Acceptable regions consisted of cells in the remainder of these rows (1–3 for above and 5–7 for below). Finally the bad regions consists of cells in the remaining rows (4–7 for the above plot and 1–4 for the below plot).

Average acceptability ratings were calculated across each of these regions; these are presented in Table 2. A 3 (region: good, acceptable, bad) × 2 (spatial relation: above and below) repeated measure analysis of variance (ANOVA) performed on these mean ratings validated the region classification and replicated Logan and Sadler (1996). There was a main effect of region, $F(2, 42) = 550.3$, $MS_e = 1.56$; a main effect of spatial relation, $F(1,21) = 6.4$, $MS_e = .50$; and a significant interaction, $F(2, 42) = 4.1$, $MS_e = .31$. Based on a critical difference of .35, for both above and below, the mean ratings for the good region ($M = 8.9$ and 8.6, respectively) were significantly higher than the mean ratings for the acceptable region ($M = 6.8$ and 6.2, re-

TABLE 2

MEAN ACCEPTABILITY RATINGS FOR ALL SUBJECTS BY REGIONS BROKEN DOWN BY ORIENTATION AND SPATIAL RELATION FOR EXPERIMENT 1

Region	Spatial relation: Above	Below
Canonical		
Good (VEO-axis)	8.9	8.6
Acceptable (VEO)	6.8	6.2
Bad	.2	.3
Noncanonical		
Good (VE-axis)	3.8	3.3
Good (O-axis)	6.1	6.0
Acceptable (VEO)	6.4	5.5
Acceptable (VE)	3.1	3.1
Acceptable (O)	4.2	3.6
Bad	.2	.2

Note. V, viewer-centered; E, environment-centered; O, object-centered.

spectively), which in turn were significantly higher than the mean ratings for the bad regions (M = .22 and .26, respectively). The interaction was due to a significant difference between above and below in the acceptable region but not in the good or bad regions.

Because the reference frames on these canonical trials were aligned, these templates are consistent with either an exclusive use of one reference frame or the use of a combination of reference frames across trials. In order to distinguish between these possibilities it is necessary to examine the spatial templates for the noncanonical trials.

Noncanonical trials. The mean acceptability ratings for each position for each spatial relation are presented in Table 1. The templates are based on a reference object that was rotated 90° counter-clockwise (consistent with Figs. 2b–2d). The data for subjects who saw the reference object with the opposite rotation were recoded by reflecting over the vertical midline.

Examination of the ratings in each region revealed very different spatial templates than for the canonical trials or for the schematic templates depicted in Figures 2b and 2c. Good, acceptable, and bad regions were designated as in Logan and Sadler (1996), first with respect to a viewer/environment template and then with respect to an object template, with such designations then combined, as shown schematically in Fig. 2d. If the viewer/environment spatial template was solely used across trials, then the good, acceptable, and bad regions should correspond to designations identified in Fig. 2b; thus, weights of 0 would be assigned to the designations on the basis of the object template in Fig. 2d. If the object spatial template was solely used across trials, then the good, acceptable, and bad regions should correspond to designations identified in Fig. 2c; thus, weights of 0 would be assigned to the designations on the basis of the viewer/environment template in Fig. 2d. However, if a mixture of these spatial templates was used across noncanonical trials, then the regions should most closely correspond to the combined designations of good, acceptable, and bad within the viewer/environment and object spatial templates; thus, positive weights would be assigned to the designations made by both templates in Fig. 2d.

This latter possibility was supported by the data. For the noncanonical spatial templates, neither the vertical axis of the viewer/environment-centered reference frame (e.g., VE-axis) nor the vertical axis of the object-centered reference frame (e.g., O-axis) served to define a region of highest acceptability that could be labeled a good region for either the above or the below spatial templates. Instead, the region of highest acceptability ratings was in the area defined as acceptable by both reference frames (the VEO acceptable region), with a gradual decline in acceptability toward the region defined as acceptable by the viewer/environment-centered reference frame alone (the VE acceptable region) or toward the region defined by the object-centered reference frame alone (the O acceptable region). Again, this was true for both above and below spatial templates. Finally, the bad regions for the above and below spatial templates were both smaller, consisting of only 15 cells, rather than the 27 that made up the bad regions for the canonical trials. Thus, the shapes and sizes of the regions for the spatial template constructed across noncanonical trials substantially differed from those constructed across canonical trials. The means averaged across each region broken down by spatial relation are presented in Table 2.

To further evaluate whether the noncanonical templates reflected a mixture of viewer/environment and object templates, we focused our analyses on the three acceptable regions: VEO, VE and O. A 3 region (VEO, VE, and O) $\times$ 2 spatial relation (above and below) repeated measures ANOVA revealed a main effect of region, $F(2,42) = 8.3$, $MS_e = 11.6$, a main effect of spatial relation, $F(1,21) = 15.6$, $MS_e = .49$, and a significant region $\times$ relation interaction, $F(2,42) = 4.2$, $MS_e = .52$. Using a critical difference of .45, for both above and below, the mean acceptability rating for the VEO regions ($M = 6.4$ and 5.5, respectively) were significantly higher than for either the O regions ($M = 4.2$ and 3.6, respectively) or the VE regions ($M = 3.1$ and 3.1, respectively). Finally, the O regions were rated as significantly higher than the VE regions. The significant interaction was due to a difference in acceptability between above and below in both the VEO and O regions but not in the VE region.

Decomposing the Noncanonical Spatial Templates

The results thus far support the idea that the spatial template constructed across noncanonical trials reflects a combination of using the viewer/environment template and the object template. We wondered whether the viewer/environment template and object template were identical (except for orientation) or whether the type of reference frame used to align the spatial template also altered its shape and/or the relative sizes of its areas. If the same spatial template is always constructed, then the shape and sizes of its regions should remain constant across the different reference frames. This is illustrated in Figs. 2b and 2c, where the same schematic template is shown albeit with a 90° rotation.

To test this idea, we examined whether the spatial templates emerging across noncanonical trials could be predicted from a combination of the same spatial template (obtained on canonical trials) once in an upright position to represent use of the viewer/environment template and once rotated 90° to represent use of the object template. If the reference frames do not alter the spatial template in ways other than orientation, then this combination should successfully predict the noncanonical spatial templates. However, if the type of reference frame serves to dramatically alter the shape or size of the regions of the spatial template, then this combination should not successfully predict the noncanonical spatial templates.

Separate regression analyses on the above and below plots suggested that the type of reference frame used to align the spatial template does not seem to alter its characteristics. The noncanonical spatial templates were well predicted from a combination of the canonical template, upright to represent the viewer/environment template and rotated 90° to represent the object template. Specifically, for above, the best fitting regression line assigned beta weights of .38 for the viewer/environment template and .58 for the object template, $R^2 = .96$. For below, the beta weights were .37 and .54, respectively, $R^2 = .90$. Such high goodness of fit measures indicate that the viewer/environment spatial template and the object template are very similar.

Individual Preferences for Reference Frame Selection

The conclusions that we have drawn thus far are based on data from all subjects in the experiment. However, this mixture could arise either across subjects or within subjects. Specifically, it is possible that some subjects exclusively used the viewer/environment-centered reference frame and other subjects exclusively used the object-centered reference frame. Averaging across these groups of subjects would produce templates that inappropriately reflected a mixture like that observed. Alternatively, it is also possible that particular subjects used a mixture of templates, switching between viewer/environment-centered reference frame and the object-centered reference frame on a trial-by-trial basis.

We looked at the data from individual subjects to determine their preferences for selecting a reference frame on noncanonical trials. Specifically, we classified subjects into one of three groups: (1) the viewer/environment/object group that used all reference frames, (2) the viewer/environment group that predominantly used the viewer/environment-centered reference frame, and (3) the object group that predominantly used the object-centered reference frame. For above, there were 7, 5, and 10 subjects in each group, respectively; for below, there were 8, 5, and 9 subjects, respectively. The classification scheme was based on the average ratings in the VE acceptable region and the O acceptable region on noncanonical trials (see Table 6 for the mean ratings on which we based our classification). Subjects preferring the viewer/environment-centered reference frame had relatively high ratings for the VE region but low ratings in the O region. In contrast, subjects preferring the object-centered reference frame had relatively high ratings for the O region but low ratings for the VE region. Subjects using all reference frames across trials had relatively high ratings for both the VE and O regions. Importantly, this classification of subjects was independent of their acceptability ratings in the VEO region, thus permitting us to compare mean ratings for this region with those for the VE and O regions.

We discuss each group briefly, examining how the preferences for particular reference frames influenced the construction of a spatial template across canonical and noncanonical trials. The mean acceptability ratings for each position for the canonical and noncanonical trials are in Tables 3, 4, and 5 for the viewer/environment/object group, the viewer/environment group, and the object group, respectively. Mean acceptability ratings averaged across regions are in Table 6. Inferential statistics for critical comparisons on the noncanonical templates are in Table 7.

Viewer/environment/object group. The spatial templates for both the canonical and the noncanonical trials are similar to the spatial templates for the overall group data on a number of characteristics: the canonical templates have good, acceptable, and bad regions, whereas the noncanonical templates have poor so-called good regions, larger acceptable regions, and smaller bad regions. In addition, for above, the mean acceptability rating for the VEO region was significantly greater than the mean rating for both the VE and O regions. For below, the mean rating for the VEO region was significantly greater than for the O region but not the VE region. Finally, the noncanonical templates were well predicted by a combination of this group's canonical template, upright to represent the viewer/environment template, and rotated 90° to represent the object template. For above, the best fitting regression line assigned beta weights of .46 to the viewer/environment template and .46 to the object template, $R^2 = .87$; for below, the beta weights were .48 and .31, respectively, $R^2 = .76$.

Viewer/Environment group. The spatial templates for the noncanonical trials are more similar to the spatial templates for canonical trials than for the viewer/environment/object group, but there are still some differences. For example, the noncanonical templates have no easily defined good region. In addition, for both above and below, the mean acceptability ratings for the VEO regions were significantly higher than for the VE regions. Finally, the noncanonical templates were well predicted by a mixture of this group's canonical template, upright for the viewer/environment template, and rotated 90° for the object template, with a greater weight assigned to the viewer/environment template. For above, the best fitting regression line assigned beta weights of .86 to the viewer/environment template and .12 to the object template, $R^2 = .95$; for below,

TABLE 3

MEAN ACCEPTABILITY RATINGS FOR ABOVE AND BELOW BY POSITION IN 7 × 7 GRID FOR CANONICAL TRIALS (TOP) AND NONCANONICAL TRIALS (BOTTOM) FOR THE VIEWER/ENVIRONMENT/OBJECT GROUP

	Spatial relation													
	Above							Below						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7
Canonical trials														
R1	8.0	8.7	8.7	9.0	8.7	7.9	6.3	0	.8	0	.3	0	1.1	0
R2	5.9	7.9	7.3	9.0	8.0	7.9	7.3	0	.1	.5	.6	0	0	.3
R3	5.6	5.1	6.6	9.0	5.3	5.4	4.4	0	.4	0	0	1.1	0	0
R4	0	1.3	0	—	.4	0	0	.6	.5	.3	—	1.5	.6	.6
R5	0	0	0	0	0	0	0	4.5	6.3	6.0	8.0	6.8	5.8	4.1
R6	0	0	0	0	0	0	0	6.3	7.0	8.1	7.8	5.4	6.8	6.6
R7	0	0	0	0	0	0	0	6.9	7.4	6.9	7.9	7.4	8.4	7.1
Noncanonical trials														
R1	7.0	6.4	6.3	4.6	5.4	6.1	3.9	0	0	0	1.4	3.4	2.4	1.9
R2	7.1	5.6	6.7	5.6	3.9	3.6	2.7	0	0	0	.6	2.5	2.5	3.4
R3	4.7	5.9	5.0	5.0	3.3	3.4	4.1	0	.3	1	0	3.3	3.5	4.6
R4	5.9	6.0	5.6	—	0	0	0	0	1.1	1.6	—	5.0	4.3	4.9
R5	4.7	5.4	2.4	0	0	0	0	3.0	2.4	4.5	5.0	5.3	4.1	5.1
R6	5.0	4.4	3.9	.7	0	0	0	3.9	5.6	5.6	4.8	5.4	5.9	5.4
R7	4.1	4.1	1.6	0	.7	0	0	5.3	4.4	6.8	3.4	4.9	4.1	5.9

Note. For all grids, the reference object was located in cell (4, 4). For noncanonical trials, the reference object was rotated 90° counter-clockwise in the picture plane. R, row; C, column.

the beta weights were .78 and .21, respectively, $R^2 = .90$.

Object group. In contrast to the other groups, the noncanonical spatial templates are very similar to the canonical spatial templates. For example, there was a definite good region that fell on the vertical axis of the reference object, and its acceptability did not differ from the acceptability of the good region on canonical trials on either the above or the below templates. In addition, there was no difference between the VEO region and the O region. Finally, the regression analyses examining the noncanonical templates as a combination of this group's canonical template upright for viewer/environment template and rotated 90° for the object template revealed only a significant contribution of the object-centered reference frame. More specifically, for above, the best fitting regression line assigned a beta weight of .94 to the object template and a nonsignificant weight of .03 to the viewer/environment template, $R^2 = .98$; for below, the beta weights were .93 and a nonsignificant −.01, respectively, $R^2 = .95$.

Summary of Groups

For subjects in the viewer/environment/object group and the viewer/environment group, ratings for regions designated acceptable by more than one reference frame (e.g., the VEO region) were higher than ratings for regions designated as acceptable only by one reference frame (e.g., the VE and the O regions). This suggests that more than one type of reference frame was used, and accordingly, the spatial template emerging across noncanonical trials was a combination of the viewer/environment and object templates used

TABLE 4

MEAN ACCEPTABILITY RATINGS FOR ABOVE AND BELOW BY POSITION IN 7 × 7 GRID FOR CANONICAL TRIALS (TOP) AND NONCANONICAL TRIALS (BOTTOM) FOR THE VIEWER/ENVIRONMENT GROUP

	Spatial relation													
	Above							Below						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7
Canonical trials														
R1	8.4	8.4	8.6	9.0	8.6	8.6	8.6	0	0	0	0	0	0	0
R2	8.2	8.2	8.4	9.0	8.6	8.4	8.0	0	0	1.0	1.8	0	0	0
R3	7.0	7.0	7.0	9.0	7.6	7.4	6.2	0	1.8	0	1.0	0	0	0
R4	.8	1.0	.4	—	0	.4	.8	0	0	0	—	0	0	0
R5	0	0	0	.4	0	0	0	3.4	6.4	7.6	9.0	8.0	6.6	5.0
R6	0	1.8	0	0	0	0	0	7.2	7.6	8.2	8.8	8.2	7.6	7.0
R7	0	0	0	1.8	0	0	0	7.8	6.6	6.8	9.0	6.6	8.2	6.2
Noncanonical trials														
R1	8.6	8.4	7.8	5.4	6.2	8.2	7.6	0	0	0	0	.6	1.8	1.0
R2	7.8	8.2	8.0	8.6	5.8	7.6	6.6	0	0	0	0	1.0	.8	.6
R3	6.2	8.4	8.0	8.6	6.0	7.6	5.6	0	0	0	0	1.8	2.6	2.8
R4	.8	1.6	1.8	—	1.0	.8	.8	0	0	0	—	2.8	2.8	2.8
R5	.2	1.0	1.2	0	0	0	0	2.8	2.8	6.4	7.2	5.4	4.2	6.4
R6	.8	.8	.4	0	0	0	0	6.6	6.8	6.4	7.0	7.4	7.2	7.4
R7	2.4	1.8	.2	0	.4	0	0	6.0	6.6	7.4	7.0	6.4	8.0	7.4

Note. For all grids, the reference object was located in cell (4, 4). For noncanonical trials, the reference object was rotated 90° counter-clockwise in the picture plane. R, row; C, column.

on individual trials. The viewer/environment and object templates were very similar (except for orientation), as indicated by the high goodness of fit attributed to predicting the noncanonical templates from a combination of the same canonical template at two orientations. Thus, the type of reference frame did not alter characteristics of the spatial template such as its shape and the relative size of its areas. Rather, the differences between these groups appeared in the relative contributions of the spatial templates to the mixture emerging on noncanonical trials. For the viewer/environment/object group, the beta weights for the viewer/environment template and the object template were relatively equal, reflecting an unbiased use of each. For the viewer/environment group, the beta weights for the viewer/environment template were much larger than those for the object template, reflecting a bias in favor of using the viewer/environment-centered reference frame that is compatible with this group's classification. What is most interesting is that despite this preference, an influence of the object-centered reference frame was nonetheless observed. Finally, in contrast to these groups, the noncanonical spatial templates for the object group were not a composite of the viewer/environment and the object templates, but rather were well predicted by use of only the object template. These subjects appeared to maintain exclusive use of the object-centered reference frame, and as such, for these subjects, the spatial template emerging across noncanonical trials was presumably the same as the spatial template used on individual trials.

Thus, Experiment 1 demonstrated that the preferences for selecting a reference frame affect the construction of spatial templates across trials,

TABLE 5

MEAN ACCEPTABILITY RATINGS FOR ABOVE AND BELOW BY POSITION IN 7 × 7 GRID FOR CANONICAL TRIALS (TOP) AND NONCANONICAL TRIALS (BOTTOM) FOR THE OBJECT GROUP

	Spatial relation													
	Above							Below						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7
	Canonical trials													
R1	6.3	6.9	7.5	9.0	6.9	6.5	6.0	0	.1	0	0	1.0	.7	0
R2	6.4	6.2	7.0	8.6	6.4	6.0	5.7	.1	.1	1.0	0	.2	1.1	.1
R3	5.2	5.4	6.3	9.0	6.9	5.3	4.4	.6	0	0	0	0	.1	.1
R4	.3	.8	1.1	—	1.4	.2	.7	0	.6	0	—	0	0	.2
R5	.7	0	0	0	.7	.5	.2	3.1	4.8	4.1	9.0	5.4	4.0	3.8
R6	.1	.8	.1	0	.1	0	.2	5.2	5.7	7.0	9.0	6.7	6.0	6.0
R7	0	.1	0	0	0	0	0	6.4	5.8	7.3	9.0	6.1	6.0	5.7
	Noncanonical trials													
R1	6.1	6.0	3.9	.7	.4	.2	.7	0	1.1	.1	.8	4.4	3.9	5.2
R2	6.5	5.3	3.7	1.1	.7	.7	.4	0	.2	0	.2	4.2	4.9	5.0
R3	7.2	6.9	6.2	1.2	.5	.5	.2	.2	0	.2	0	5.8	6.2	7.3
R4	8.5	9.0	8.6	—	0	0	0	0	.6	0	—	8.9	8.9	9.0
R5	7.0	6.9	6.2	0	.2	.1	.2	.6	0	.3	.2	5.6	5.8	6.8
R6	6.3	6.2	5.3	.4	.9	.2	0	0	.3	.2	.1	4.7	5.1	6.1
R7	5.3	5.3	4.4	.3	.5	.3	.1	0	0	.2	.3	3.4	4.6	4.7

Note. For all grids, the reference object was located in cell (4, 4). For noncanonical trials, the reference object was rotated 90° counter-clockwise in the picture plane. R, row; C, column.

with the manner in which space is parsed into good, acceptable, and bad regions directly influenced by the degree to which subjects switched between the different types of reference frames. Further implications of these results are discussed under General Discussion.

EXPERIMENT 2

Given that multiple reference frames are available for assigning a direction to a spatial relation, it is important to understand the online process of selecting a reference frame. Carlson-Radvansky and Irwin (1994) examined this issue using a sentence/picture verification task (e.g., Clark & Chase, 1972) with pictures in which the vertical axes of the different reference frames were dissociated, thus assigning competing directions to the spatial term ''above.'' The conditions of interest included a located object placed (1) above a rotated reference object according to the object-centered reference frame, (2) above according to coincident upright viewer/environment-centered reference frames, (3) not above according to any reference frame, and (4) above an upright reference object according to all three coincident reference frames. Response times and acceptance rates were collected for judgments of the acceptability of sentences containing the spatial term ''above'' as descriptions of the relation between the objects in the picture.

For upright subjects, correct ''yes'' responses were significantly slower when the frames assigned different directions than when they were aligned and assigned the same direction. This difference in response time is an indication of competition. The use of one reference frame (e.g., viewer/environment-centered) was slowed when the other refer-

TABLE 6

MEAN ACCEPTABILITY RATINGS BY REGIONS BROKEN DOWN BY ORIENTATION AND SPATIAL RELATION AND GROUP FOR EXPERIMENT 1

	Group					
	Viewer/environment/object		Viewer/environment		Object	
Region	Above	Below	Above	Below	Above	Below
Canonical						
Good (VEO-axis)	9.0	7.9	9.0	8.9	8.9	9.0
Acceptable (VEO)	6.9	6.6	8.0	6.9	6.2	5.5
Bad	.1	.3	.3	.2	.3	.2
Noncanonical						
Good (VE-axis)	5.0	4.4	7.5	7.1	1.0	.2
Good (O-axis)	5.8	4.7	1.4	2.7	8.7	8.9
Acceptable (VEO)	6.1	5.1	7.9	6.6	5.8	5.2
Acceptable (VE)	4.0	4.6	6.8	5.8	.5	.2
Acceptable (O)	4.0	3.0	1.0	1.4	5.9	5.2
Bad	.1	.4	.2	0	.2	.2

Note. V, viewer-centered; E, environment-centered; O, object-centered.

ence frame (e.g., object-centered) indicated a conflicting direction for the same spatial term, relative to when the reference frames were aligned.[4] These results indicate that multiple reference frames are initially active and compete to assign directions to spatial relations.

The primary question in Experiment 2 was whether the activation of multiple reference frames on a single noncanonical trial would result in the construction of multiple spatial templates, one for each active reference frame. This would suggest that spatial template construction occurs simultaneous with or as a consequence of reference frame activation prior to the selection of a reference frame. In contrast, it is possible that only a single spatial template is constructed on a noncanonical trial that is then aligned with the chosen reference frame. This would suggest that spatial template construction occurs after reference frame selection, and is therefore not influenced by the initial simultaneous activation of multiple reference frames.

To distinguish between these possibilities, Experiment 2 employed a speeded sentence/picture verification task (e.g., Clark and Chase, 1972). Applying the logic from Experiment 1, if multiple spatial templates are constructed within a trial when multiple reference frames are active, then there should be evidence of easier access to regions considered acceptable within multiple spatial templates than to regions considered acceptable within one template and bad within another template. This should result in faster and more accurate ‘‘yes’’ responses to placements of the located object within the VEO region than within the VE or O regions. Similarly, it should be harder to judge a region as unacceptable if it is con-

[4] While this comparison is not sufficient by itself as an indicator of competition, a number of comparisons were made across conditions, all of which supported the idea that multiple reference frames were active and competed during spatial term assignment. For the sake of brevity, these are not reviewed here; see Carlson-Radvansky and Irwin (1994) for details.

TABLE 7

INFERENTIAL STATISTICS FOR CRITICAL COMPARISONS BROKEN DOWN BY GROUP AND SPATIAL RELATION FOR NONCANONICAL REGIONS IN EXPERIMENT 1

	Spatial relation	
Comparisons	Above	Below
Viewer/environment/object group		
VEO acceptable vs VE acceptable	6.1 vs 4.0; $t(6) = 3.9$*	5.1 vs 4.6; $t(7) < 1$
VEO acceptable vs O acceptable	6.1 vs 4.0; $t(6) = 4.5$*	5.1 vs 3.0; $t(7) = 2.9$*
Viewer/environment group		
VEO acceptable vs VE acceptable	7.9 vs 6.8; $t(4) = 3.0$*	6.6 vs 5.8; $t(4) = 3.7$*
Object group		
VEO acceptable vs O acceptable	5.8 vs 5.9; $t(9) < 1$	5.2 vs 5.2; $t(8) < 1$

Note. V, viewer-centered; E, environment-centered; O, object-centered.
* $p \leq .05$.

sidered acceptable within one template and bad within the other template than for a region considered bad within both spatial templates. This should result in slower and less accurate ‘‘no’’ responses to placements of the located object within the VE region and O region than within a bad region.

In contrast, if only one spatial template is constructed on any given trial, then whether the placement fell within an acceptable or bad region on the other spatial template should not influence performance. This should result in no systematic differences in the speed or accuracy of making ‘‘yes’’ responses to placements of the located object within the VEO region relative to the VE and O regions. Similarly, there should be no difference in speed or accuracy at making ‘‘no’’ responses to placements of the located object within the O region or VE region relative to placements within a bad region.

The strongest test of the construction of multiple spatial templates within a trial would be to look for the influence of a spatial template that the subject did not intend to construct. Experiment 1 showed that the influence of a spatial template across trials is related to how often people selected the different reference frames. Therefore, we decided to control the frequency of use by explicitly instructing subjects on which reference frames to select. Accordingly, we had three groups of subjects: the viewer/environment/object group that was told to respond on the basis of all reference frames; the viewer/environment group that was told to respond only on the basis of the viewer/environment-centered reference frame; and the object group that was told to respond only on the basis of the object-centered reference frame. This is a strong test because responses for the latter two groups require the construction of just one spatial template. If, however, multiple spatial templates are constructed within a trial as a function of the activation of multiple reference frames, then there should be evidence of the noninstructed template facilitating ‘‘yes’’ and hindering ‘‘no’’ responses to placements that occur within its acceptable region.

Method

Subjects

Ninety-nine University of Notre Dame undergraduates participated in exchange for partial credit in an introductory psychology class. Using random assignment, 26 subjects were assigned to the viewer/environment/object group, 43 to the viewer/environment group, and 35 to the object group. Different numbers of subjects had to be excluded from each group because of failures to follow instructions, such as accepting placements of the located object according to the object-centered reference frame when instructed to only use the viewer/environment-centered reference frame. This yielded acceptable data from 21 subjects in the viewer/environment/object group, 33 in the viewer/environment group, and 29 in the object group.

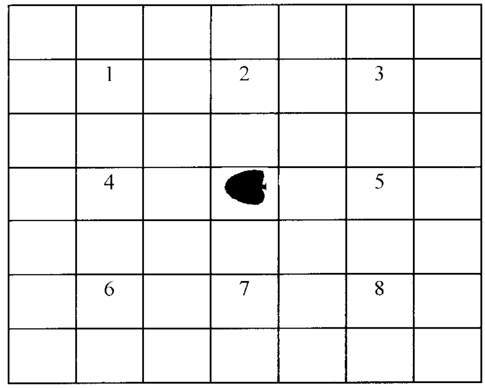

FIG. 3. Illustration of the eight placements of the located object for a noncanonical reference object in Experiment 2.

Stimuli

A number of changes were made in the stimuli for Experiment 2. First, the located object appeared once within each of the following five critical regions: for above, the VEO, VE, and O acceptable regions, a good region defined along the axis of the viewer/environment-centered reference frame (henceforth, the VE-axis), and a good region defined along the axis of the object-centered reference frame (henceforth, the O-axis). For below, the same corresponding critical regions were defined: VEO, VE, and O acceptable regions and VE-axis and O-axis good regions. Combining these placements across above and below yielded eight locations in the matrix, corresponding to cells (2,2), (2,4), (2,6), (4,2), (4,6), (6,2), (6,4), and (6,6). An illustration of these eight locations surrounding a noncanonical reference object is provided in Fig. 3. Locations 1, 2, and 3 represent placements for above and 6, 7, and 8 for below according to the viewer/environment-centered reference frame, whereas locations 1, 4, and 6 represent placements for above and 3, 5, and 8 represent placements for below according to the object-centered reference frame. Therefore, the VEO region is represented by location 1 for above and by location 8 for below. The VE region is represented by location 3 for above and location 6 for below. The O region is represented by location 6 for above and location 3 for below. The VE-axis region is represented by location 2 for above and 7 for below. Finally, the O-axis region is represented by location 4 for above and 5 for below.

To compensate for the limited number of responses per region, the number of picture stimuli (e.g., reference objects) was increased to 12. These 12 reference objects were derived from clip art pictures taken from CorelDraw! 4.0 and included a globe, lightbulb, pumpkin, tomato, pocketwatch, place setting, pot of gold, peach, bear, woman's face, tree, and a bird.

Design

All subjects received trials in which the central reference object was upright (canonical trials) and rotated 90° (noncanonical trials). Of the 12 reference objects, half were rotated clockwise and half counter-clockwise. The spatial terms above and below were used. In all, there were 384 trials, constructed from the following variables: 2 orientations (canonical and noncanonical) × 2 spatial terms (above, below) × 8 locations × 12 pictures. The trials were presented in a different random order to each subject.

Procedure

Subjects were instructed that they would be shown sentence–pictures pairs and would be asked to determine whether the sentence was an acceptable description of the picture as quickly and as accurately as possible. As in Experiment 1, at the beginning of the trial a sentence of the form ''The square is ____ [the object]'' was presented, where the spatial relation was inserted in place of the blank line and the name of the reference object was inserted in place of the bracketed text. The sentence appeared centered on the computer screen for 2 s, and was followed by a picture of a central reference object and a located object (a box) positioned in one of the eight positions on the grid. The picture remained on the screen until the subject responded by pressing designated ''yes'' and ''no'' keys on the keyboard. All subjects were told that they should respond as quickly and as accurately as possible. Response time was recorded from the onset of the picture until the response key press.

In terms of the instruction manipulation, all subjects were shown a display similar to Fig. 3 with a canonical and noncanonical reference object surrounded by the eight numbered probe locations. The locations were classified as representing a location for above or below according to the environment-centered, viewer-centered, and/or the object-centered reference frames. For example, typed below the picture of the noncanonical reference object were statements indicating that positions 1, 2, 3 were above according to the environment and the viewer and that positions 1, 4, 6 were above according to the object. There was no explicit mention that position 1 was therefore above according to all three reference frames, although this could be inferred.

Subjects in the viewer/environment/object group were told to decide that a sentence was an acceptable description of the picture if the square in the picture was above or below the second object according to any interpretation of above or below. Subjects in the viewer/environment group were told to decide ''yes'' only if the square was above or below according to the environment or themselves as the viewer, and to decide no if it was above only according to the object. Finally, subjects in the object group were told to decide ''yes'' only if the square was above or below according to the object and to decide ''no'' if it was above only according to the environment or themselves as the viewer.

For all subjects, each of the eight locations in the figure was then explicitly indicated, and the appropriate response was discussed in accordance with the instructions. It was clear that these locations were indicated by way of explaining the pattern of responding (i.e., an example of above according to an object-centered frame), rather than by way of indicating responses to these particular locations. Indeed, in the experimental trials, objects were rotated both counter-clockwise (as in the figure) and clockwise, thus requiring responses with respect to reference frames rather than specific screen locations. Subjects went through an initial response key learning routine in which the word ''yes'' or ''no'' appeared centered on the computer screen and subjects pressed the appropriate response key. This was followed by a block of five practice trials. Trials were self-paced, and the experiment took about 45 min to complete.

Results and Discussion

Because all reference frames were aligned when the reference object was upright, the canonical trials cannot distinguish between the construction of multiple spatial templates versus the construction of a single spatial template within a trial. Consequently, we focus on the noncanonical trials. Mean percentage correct and response times for correct ''yes'' responses broken down by region and spatial term for each group are presented in Table 8. Mean percentage correct and response times for correct ''no'' responses for the viewer/environment group and the object group are presented in Table 9. The details of the specific statistical tests performed on the response times and accuracy data are presented in Tables 10, 11, and 12 for the viewer/environment/object group, the viewer/environment group and the object group, respectively.

TABLE 8

MEAN PERCENTAGE CORRECT AND RESPONSE TIMES (IN MS) FOR CORRECT "YES" RESPONSES FOR NONCANONICAL TRIALS BROKEN DOWN BY REGION, SPATIAL RELATION, AND GROUP FOR EXPERIMENT 2

	Group					
	Viewer/environment/ object		Viewer/environment		Object	
Region	Above	Below	Above	Below	Above	Below
	Percentage correct					
Good (VE-axis)	94	89	97	92	—	—
Good (O-axis)	98	92	—	—	99	94
Acceptable (VEO)	99	95	96	95	98	93
Acceptable (VE)	79	71	95	90	—	—
Acceptable (O)	85	81	—	—	98	93
	Response times					
Good (VE-axis)	1009	1180	710	833	—	—
Good (O-axis)	1003	1206	—	—	867	1008
Acceptable (VEO)	984	1137	751	848	837	1041
Acceptable (VE)	1157	1341	757	879	—	—
Acceptable (O)	1160	1345	—	—	895	1013

Note. V, viewer-centered; E, environment-centered; O, object-centered.

Viewer/Environment/Object Group

Subjects in this group were instructed to use all reference frames as the basis of their acceptability judgments. Consequently, "yes" responses to placements of the located object within the VEO, VE, O, VE-axis, and O-axis regions were compared. "No" responses were not analyzed because they corresponded only to incorrect placements according to all reference frames, and hence were not informative.

For percentage correct, there was a main effect of region. Based on a critical difference of 6%, access to the VEO region (M = 97%) was more accurate than access to the VE region (M = 75%), the O region (M = 83%), and the VE-axis region (M = 91%), but did not differ from access to the O-axis region (M = 95%). There was also a main effect of spatial relation, with responses to above (M = 91%) significantly more accurate than responses to below (M = 85%). Similarly, for response times, there was a main effect of region. Based on a critical difference of 102 ms, access to the VEO region (M = 1060 ms) was faster than access to the VE region (M = 1249 ms) and the O region (M = 1253 ms), but did not differ from access to the VE-axis region (M = 1095 ms) or the O-axis region (M = 1105 ms). There was also a main effect of spatial relation, with responses to above (M = 1063 ms) significantly faster than responses to below (M = 1242 ms).

Viewer/Environment Group

"Yes" responses. "Yes" responses to placements of the located object in the VEO, VE, and VE-axis regions were compared. For percentage correct, there was a main effect of region, a main effect of spatial relation, and a marginally significant interaction between region and spatial relation. Based on a critical difference of 3%, for above, there was no difference in access to the three regions: VEO region (M = 96%),

TABLE 9

MEAN RESPONSE TIMES (IN MS) AND PERCENTAGE CORRECT (IN PERCENTAGES) IN PARENTHESES FOR ''NO'' RESPONSES FOR THE CRITICAL NONCANONICAL GOOD, ACCEPTABLE, AND CONTROL REGIONS IN EXPERIMENT 2

	Spatial relation	
Region	Above	Below
Viewer/environment group		
Good O-axis	856 (96)	881 (97)
Control O-axis	824 (99)	841 (99)
Acceptable O	858 (96)	913 (94)
Control O	866 (98)	911 (96)
Object group		
Good VE-axis	899 (96)	1011 (97)
Control VE-axis	944 (99)	917 (99)
Acceptable VE	1008 (98)	1093 (94)
Control VE	1010 (99)	1093 (97)

Note. V, viewer-centered; E, environment-centred; O, object-centered.

VE-axis region (M = 97%), and VE region (M = 95%). However, for below, access to the VEO region (M = 95%) was more accurate than access to both the VE-axis region (M = 92%) and the VE region (M = 89%). For response times, there was a main effect of region by subjects but not by items. Based on a critical difference of 46 ms, access to the VEO region (M = 799 ms) did not differ from access to the to the VE-axis region (M = 771 ms) or the VE region (M = 818 ms), whereas these latter two conditions did differ. There was also a main effect of spatial relation, with responses to above (M = 739 ms) faster than responses to below (M = 854 ms).

''No'' responses. Subjects were instructed to reject placements of the located object that fell either along the O-axis of the object-centered reference frame or in the O acceptable region. However, if an object spatial template was constructed despite instructions to use only the viewer/environment-centered reference frame, then rejection of these placements should be more difficult than rejection of placements of the located object in bad regions. To test this idea, separate analyses were conducted on the correct ''no'' responses, comparing good versus bad placements in the object template. The bad placements were matched in terms of distance and direction from the reference object. For example, based on the noncanonical orientation of the reference object in Fig. 3, for above the good placement was position 4 and the bad placement was

TABLE 10

INFERENTIAL STATISTICS FOR EFFECTS OF REGION AND SPATIAL RELATION ON RESPONSE TIME AND ACCURACY DATA FOR THE VIEWER/ENVIRONMENT/OBJECT GROUP IN EXPERIMENT 2

Analysis	Response	DV	Factor	Inferential statistics	Significance
Region × Relation	Yes	Acc	**Region:**	$\mathbf{F_1(4, 80) = 24.0\ MS_e = .015}$	*
				$\mathbf{F_2(4, 44) = 39.0,\ MS_e = .006}$	*
			Relation:	$F_1(1, 20) = 14.7, MS_e = .01$	*
				$F_2(1, 11) = 8.7, MS_e = .007$	*
			Interaction:	Fs < 1.4	ns
Region × Relation	Yes	RT	**Region:**	$\mathbf{F_1(4, 80) = 12.4,\ MS_e = 28435}$	*
				$\mathbf{F_2(4, 44) = 12.1,\ MS_e = 18685}$	*
			Relation:	$F_1(1, 20) = 36.8, MS_e = 45796$	*
				$F_2(1, 11) = 50.7, MS_e = 19594$	*
			Interaction:	Fs < 1	ns

Note. DV, dependent variable; Acc, percentage correct; RT, response time in ms; F_1, subjects analysis; F_2, items analysis.

* $p < .05$.

ns, $p > .10$.

TABLE 11

INFERENTIAL STATISTICS FOR EFFECTS OF REGION AND SPATIAL RELATION ON RESPONSE TIME AND ACCURACY DATA FOR THE VIEWER/ENVIRONMENT GROUP IN EXPERIMENT 2

Analysis	Response	DV	Factor	Inferential statistics	Significance
Region × Relation	Yes	Acc	**Region:**	$\mathbf{F_1(2, 64) = 2.3, MS_e = .007}$	†
				$\mathbf{F_2(2, 22) = 7.3, MS_e = .001}$	*
			Relation:	$F_1(1, 32) = 11.2, MS_e = .007$	*
				$F_2(1, 11) = 15.0, MS_e = .002$	*
			Interaction:	$F_1(2, 64) = 2.4, MS_e = .004$	†
				$F_2(2, 22) = 3.0, MS_e = .001$	†
Region × Relation	Yes	RT	**Region:**	$\mathbf{F_1(2, 64) = 3.3, MS_e = 10877}$	*
				$\mathbf{F_2 = 1.4}$	**ns**
			Relation:	$F_1(1, 32) = 82.2, MS_e = 7956$	*
				$F_2(1, 11) = 95.7, MS_e = 2716$	*
			Interaction:	*F*s < 1	ns
Placement × Relation in good region	No	Acc	**Placement:**	$\mathbf{F_1(1, 32) = 3.1, MS_e = .011}$	†
				$\mathbf{F_2(1, 11) = 15.5, MS_e = .001}$	*
			Relation:	*F*s < 1.1	ns
			Interaction:	*F*s < 1.1	ns
Placement × Relation in good region	No	RT	**Placement:**	$\mathbf{F_1(1, 32) = 5.5, MS_e = 7829}$	*
				$\mathbf{F_2(1, 11) = 3.2, MS_e = 2010}$	†
			Relation:	*F*s < 1.1	ns
			Interaction:	*F*s < 1.1	ns
Placement × Relation in acceptable region	No	Acc	**Placement:**	$\mathbf{F_1(1, 32) = 3.1, MS_e = .006}$	†
				$\mathbf{F_2(1, 11) = 4.2, MS_e = .001}$	†
			Relation:	$F_1(1, 32) = 4.2, MS_e = .003$	*
				$F_2(1, 11) = 4.5, MS_e = .001$	†
			Interaction:	*F*s < 1.1	ns
Placement × Relation in acceptable region	No	RT	**Placement:**	***F*s < 1.1**	**ns**
			Relation:	$F_1(1, 32) = 4.2, MS_e = 19303$	*
				$F_2(1, 11) = 7.1, MS_e = 4199$	*
			Interaction:	*F*s < 1.1	ns

Note. DV, dependent variable; Acc, percentage correct; RT, response time in ms; F_1, subjects analysis; F_2, items analysis.

* $p < .05$.

† $.05 < p < .10$.

ns, $p > .10$.

position 5; for below these positions were reversed. For percentage correct, there was a main effect of placement, with ''no'' responses for good placements (M = 96%) less accurate than ''no'' responses for bad placements (M = 99%). For response times, there was a only a main effect of placement, with ''no'' responses to good placements (M = 869 ms) slower than ''no'' responses to bad placements (M = 833 ms).

Similar analyses compared the correct ''no'' responses for placements of the located object within acceptable regions of the object template with placements within bad regions. For above, the acceptable region was represented by position 6 and the bad region by position 8. For below, these were positions 3 and 1, respectively. For percentage correct, there was a marginal main effect of placement, with ''no'' responses for acceptable placements (M = 95%) less accurate than ''no'' responses for bad placements (M = 97%). There was also a main effect of spatial relation, with ''no'' responses to above (M = 97%) more accurate than ''no'' responses to

TABLE 12

INFERENTIAL STATISTICS FOR EFFECTS OF REGION AND SPATIAL RELATION ON RESPONSE TIME AND ACCURACY DATA FOR THE OBJECT GROUP IN EXPERIMENT 2

Analysis	Response	DV	Factor	Inferential statistics	Significance
Region × Relation	Yes	Acc	**Region:**	**Fs < 1**	**ns**
			Relation:	$F_1(1, 28) = 30.9$, $MS_e = .003$	*
				$F_2(1, 11) = 25.9$, $MS_e = .002$	*
			Interaction:	Fs < 1	ns
Region × Relation	Yes	RT	**Region:**	**Fs < 1**	**ns**
			Relation:	$F_1(1, 28) = 59.4$, $MS_e = 17439$	*
				$F_2(1, 11) = 59.9$, $MS_e = 6651$	*
			Interaction:	$F_1(2, 56) = 3.3$, $MS_e = 8713$	*
				$F_2(2, 22) = 6.6$, $MS_e = 2675$	*
Placement × Relation in good region	No	Acc	**Placement:**	**$F_1(1, 28) = 2.3$, $MS_e = .004$**	**ns**
				$F_2(1, 11) = 4.1$, $MS_e = .001$	†
			Relation:	Fs < 1	ns
			Interaction:	Fs < 1	ns
Placement × Relation in good region	No	RT	**Placement:**	**$F_1(1, 28) = 2.8$, $MS_e = 6195$**	**ns**
				$F_2 < 1.4$	**ns**
			Relation:	$F_1(1, 28) = 3.0$, $MS_e = 17482$	†
				$F_2(1, 11) = 5.4$, $MS_e = 4585$	*
			Interaction:	$F_1(1, 28) = 16.2$ $MS_e = 8678$	*
				$F_2(1, 11) = 9.3$, $MS_e = 6074$	*
Placement × Relation in acceptable region	No	Acc	**Placement:**	**$F_1(1, 11) = 4.4$, $MS_e = .003$**	†
				$F_2(1, 11) = 4.1$, $MS_e = .001$	†
			Relation:	$F_1(1, 28) = 17.1$, $MS_e = .002$	*
				$F_2(1, 11) = 18.2$ $MS_e = .001$	*
			Interaction:	Fs < 1	ns
Placement × Relation in acceptable region	No	RT	**Placement:**	**Fs < 1**	**ns**
			Relation:	$F_1(1, 28) = 13.0$, $MS_e = 15828$	*
				$F_2(1, 11) = 14.7$, $MS_e = 6214$	*
			Interaction:	Fs < 1	ns

Note. DV, dependent variable, Acc, percentage correct; RT, response time in ms; F_1, subjects analysis; F_2, items analysis.
* $p < .05$.
† $.05 < p < .10$.
ns, $p > 10$.

below (M = 95%). For response times, there was only a main effect of spatial relation, with ‘‘no’’ responses to above (M = 862 ms) significantly faster than ‘‘no’’ responses to below (M = 912 ms).

Object Group

‘‘Yes’’ responses. ‘‘Yes’’ responses to placements of the located object within the VEO, O, and O-axis regions were compared. For percentage correct, there was only a main effect of spatial relation, with responses for above (M = 98%) significantly more accurate than responses for below (M = 93%). For response times, there was no effect of region, a main effect of spatial relation, and a significant interaction between region and spatial relation. Based on a critical difference of 50 ms, for above, access to the VEO region (M = 837 ms) was significantly faster than access to the O region (M = 895 ms), but did not differ from access to the O-axis region (M = 867 ms). For below, there were no significant differences in access to the three regions, al-

though it should be noted that the pattern was very different, with responses to the VEO region generally slower than responses to the O region.

''No'' responses. ''No'' responses to good versus bad placements within the viewer/environment template were compared. The bad placements were matched in terms of distance and direction from the reference object. For example, for above the good placement was position 2 and the bad placement was position 7; for below these positions were reversed. For percentage correct, there was a marginally significant effect of placement in the items analysis, with responses to the good region (M = 98%) less accurate than responses to the bad region (M = 100%). For response times, there was a main effect of spatial relation and a significant interaction between placement and spatial relation. Based on a critical difference of 49 ms, for above, there was no significant difference between responses to good (M = 899 ms) and bad placements (M = 944 ms); however, for below, responses to good placements (M = 1011 ms) were significantly slower than responses to bad placements (M = 917 ms).

Similar analyses compared the correct ''no'' responses for acceptable versus bad placements. For above, the acceptable region was represented by position 3 and the bad region by position 8. For below, these positions were 6 and 1, respectively. For percentage correct, there was a main effect of placement, with ''no'' responses to acceptable placements (M = 96%) less accurate than ''no'' responses to bad placements (M = 98%). In addition, there was a main effect of spatial relation, with ''no'' responses to above (M = 99%) significantly more accurate than ''no'' responses to below (M = 96%). For response times, there was only a main effect of spatial relation, with ''no'' responses to above (M = 1009) significantly faster than to below (M = 1093).

Overall Summary

Across all groups, a consistent influence of multiple spatial templates was demonstrated within a trial, with the strength of this influence mediated by the type of reference frame that governed responding. More specifically, the influence of the object template on the viewer/environment group was stronger than the influence of the viewer/environment template on the object group. Such differential influence replicates the pattern found in Experiment 1. The important point of Experiment 2 is that despite such preferences for using one reference frame over another, given explicit instructions on which reference frames to use, performance across all groups consistently indicated the construction of multiple spatial templates. This finding suggests that spatial template construction operates during reference frame selection, with the activation of multiple reference frames resulting in the construction of multiple spatial templates.

GENERAL DISCUSSION

The use of spatial relations requires the selection of a reference frame and the construction of a spatial template. A spatial template is applied and oriented on the basis of a reference frame, thus delineating regions of space that correspond to good, acceptable, and bad uses of the spatial relation. The present experiments examined the influence of two aspects of reference frame selection on spatial template construction. Experiment 1 examined the influence of preferences for particular types of reference frames on the construction of spatial templates across trials. The results demonstrated that the preferences that people have for selecting particular types of references frames are directly reflected in the manner in which they parsed up space across noncanonical trials in which the object-centered reference frame was dissociated from the viewer/environment-centered reference frame. More specifically, for subjects in the viewer/environment/object group who selected the viewer/environment-centered reference frame on some trials and the object-centered reference frame on other trials, the noncanonical spatial templates emerged from a rather evenly weighted mixture of the two spatial templates. In contrast, for subjects in the object group who predominantly used the object-centered reference frame, the noncanonical spatial templates were well predicted by only the object template. The templates for the viewer/environment group were intermediate, showing a greater influence of the viewer/environment template with a small but significant influence of the object template.

The second aspect of reference frame selection that was investigated was how the on-line selection of a reference frame influenced the construction of a spatial template within a trial. Carlson-Radvansky and Irwin (1994) showed that dissociated reference frames were simultaneously active and competed to assign directions to spatial relations. Experiment 2 examined whether multiple spatial templates would be constructed within a trial as a consequence of such simultaneous activation. A consistent effect of multiple spatial templates emerged, although the strength of this effect was mediated by the particular reference frame in use. Generally, acceptance of a location in a region defined as acceptable within more than one spatial template was faster and more accurate than acceptance of a location in a region defined as acceptable within one template and bad within another. Moreover, rejection of a location in a region defined as good or acceptable within a template that was not to be constructed was slower and more difficult than rejection of a location defined as bad within that template.

In the remainder of the General Discussion we focus on the implications of these results with respect to: (1) spatial template construction, (2) reference frame selection, (3) the relationship between these process, and (4) the basic steps for using spatial relations.

Implications for Spatial Template Construction

Using regression analyses, Experiment 1 showed that the same spatial template was constructed when the viewer/environment-centered reference frame was selected as when the object-centered reference frame was selected, suggesting that the shapes and sizes of the spatial templates do not vary across type of reference frame. This raises the possibility that there may be a one to one correspondence between spatial relations and spatial templates. However, Logan and Sadler (1996) demonstrated that the spatial templates for certain classes of spatial relations were very similar. For example, the spatial templates for above, below, over, under, left, and right all had similar shapes but differed in axis orientation and direction; likewise, in Experiment 1, the shapes of the spatial templates for above and below were largely similar, despite differences in direction. Moreover, Logan and Sadler found that the spatial templates for the relations next to, away from, near to, and far from all shared the same shape, but that this shape differed from the shape observed with above, over, left, etc. Such findings suggest that spatial templates should be defined with respect to their shape, with orientation and direction being open parameters that are set by the particular spatial relation (see also Landau & Jackendoff, 1993). Of course, this then requires an understanding of the characteristics that define the shape of a given spatial template (for some ideas see Herskovits, 1986; Vandeloise, 1991; Regier, 1996).

Implications for Reference Frame Selection

As outlined in the introduction, one of the first steps in determining the location of an object that is specified in relation to a reference object is selecting a reference frame to be imposed on the reference object. Carlson-Radvansky and Irwin (1994) showed that during reference frame selection, there is simultaneous activation of multiple reference frames. The present experiments speak to an open issue stemming from this work, specifically whether such simultaneous activation is automatic (i.e., occurs without intention). The results of Experiment 2 suggest that it is. The most important data in this respect are the accuracy and response time results from groups instructed to use only one reference frame whose data nonetheless showed a consistent influence from the nonintended reference frame. Carlson-Radvansky (1997) provides a further test of this idea by examining the simultaneous activation of multiple reference frames when they are aligned and assign the same direction to a spatial relation.

The Relationship between the Processes

Part of the motivation of Experiment 2 was to determine whether spatial template construction occurred after a reference frame was selected, such that only a single spatial template would be constructed on any given trial, or whether multiple spatial templates would be constructed during reference frame selection, one for each active reference frame. The data from Experiment 2 support the multiple spatial template account. Given that construction occurs during selection, what is the relationship between these processes? When multiple spatial templates are constructed, the parse of space around the reference object is best represented as a composite template that is a simple weighted sum of all of the existing templates for a given spatial relation, as suggested by the regression analyses of Experiment 1. One possibility is that the selection of a reference frame serves to assign weights to the templates, such that the template corresponding to the selected frame would be assigned relatively high weights and the remaining templates would be assigned relatively low weights. We qualify these weights as relatively higher and lower because the results of Experiment 2 suggest that they cannot be freely set to 0 in response to instructions. Instead, as reflected in the data from Experiment 1, there are baseline preferences for using particular reference frames that can be pushed around, but are nonetheless bounded. An alternative possibility is that weights are assigned to templates in accordance with the activation level of the particular reference frames. This is a matter for further investigation. Regardless of how the weights are assigned, they can be interpreted as reflecting preferences for using particular reference frames to assign directions to spatial relations.

What do we know about these preferences? Experiments 1 and 2 suggest that the object-centered reference frame was relatively more dominant than the viewer/environment-centered reference frame, which is at odds with Carlson-Radvansky and Irwin (1993, 1994) who consistently found higher acceptability ratings and faster and more accurate response times for using the viewer/environment-centered reference frame over the object-centered reference frame. One difference was that the current experiments used displays containing only the reference and located objects, whereas the Carlson-Radvansky and Irwin studies used displays containing whole scenes with multiple objects and typically a horizon line, thus emphasizing the environment. Such display characteristics could influence the preferences for using the different reference frames.

More generally, these differing preferences are related to the idea that sources of information that define the orientation of each type of reference frame are weighted (e.g., Attneave & Reid, 1968; Corballis, Nagourney, Shetzer, & Stefanatos, 1978; Friederici & Levelt, 1990; Levelt, 1984; McMullen & Jolicoeur, 1990). For example, a typical finding in the mental rotation literature is that dissociation of the viewer-centered reference frame from the environment-centered reference frame through use of a head tilt manipulation results in mental rotations to a point between environmental upright and retinal upright (e.g., Attneave and Reid, 1968; Corballis et al., 1978; McMullen & Jolicoeur, 1990). Similarly, Levelt has discussed how different sources of information are combined to determine acceptable uses of spatial relations (e.g., Levelt, 1984; Friederici & Levelt, 1990). The contribution of our work is to suggest an account of how such preferences are manifest. Specifically, we believe that preferences for using particular reference frames are exhibited through the weights assigned to the spatial templates, such that when they are combined, a composite map of space surrounding the reference object reflects such biases.

Basic Steps for Using Spatial Relations

A starting point for this research was noting what was missing from the sequence of basic steps for using spatial relations. Based on the current experiments, a new sequence would now include the following: (a) Identify the reference object; (b) superimpose multiple reference frames; (c) construct spatial templates and align them to the relevant reference frames; (d) select a reference frame; (e) combine templates into a composite template, taking into account their weights; (f) search the composite template by calculating goodness of fit measures for the located object on each position within the template; and (g) determine whether the goodness of fit measure for the located object is high, reflecting placement in a good or acceptable region or low, reflecting placement in a bad region. We suggest that this sequence be interpreted as a list of necessary steps without any claim as to their independence or strict serial nature. Moreover, we do not believe that this sequence is complete, or that each step has been fully explicated. However, we do think that it offers a promising framework within which to focus future research.

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