

## Research Article

## INHIBITION ACCOMPANIES REFERENCE-FRAME SELECTION

Laura A. Carlson-Radvansky and Yuhong Jiang

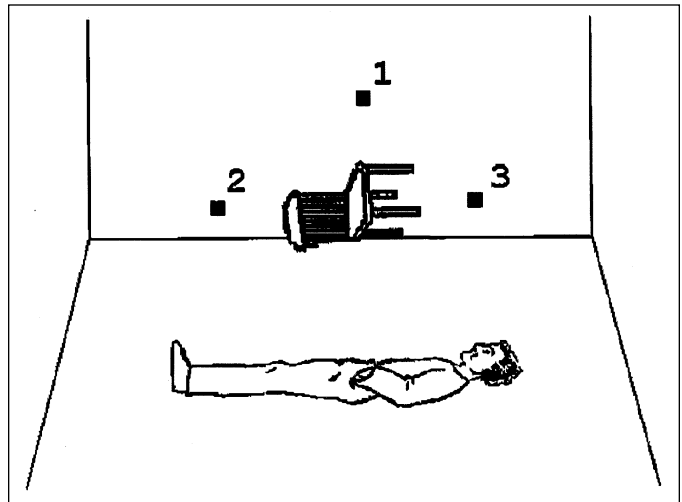
University of Notre Dame

**Abstract**—Spatial relational terms are ambiguous because they can be defined by different and sometimes conflicting frames of reference. Previous research has suggested that multiple reference frames are simultaneously active before a reference frame is selected. Two experiments examined the on-line selection of a reference frame to determine whether it is assisted by inhibition. These experiments used a negative-priming paradigm in which access to a reference frame was assessed on trial  $n$  when that reference frame was either available but not selected or not available on trial  $n - 1$ . Significant negative priming was observed; it operated along the axis of the reference frame, encompassing both endpoints. In addition, reference-frame selection seems to be independent of object selection. We cast these findings within the view of negative priming as an inhibitory mechanism, and discuss their implications for the use of spatial relations.

Spatial relations, such as “above,” are ambiguous because they can be defined according to various and sometimes conflicting sources of information. For example, Figure 1 shows a reclining person looking at an overturned chair. The person is trying to determine where “above” is; the different possibilities are represented by the three boxes. Specifically, Box 1 is above according to an *absolute* reference frame whose vertical axis is oriented with respect to gravity. Box 2 is above according to an *intrinsic* reference frame whose vertical axis is oriented with respect to the predefined sides of the chair. Box 3 is above according to a *relative* reference frame whose vertical axis is oriented with respect to the head and feet of the person viewing the scene (see Levinson, 1996, for formal definitions). Reference frames are applied to a *reference object* (i.e., the chair) and assist in the search for a *located object* (i.e., the box).

Previous research has shown that multiple reference frames are simultaneously active prior to selection. For example, in a previous study (Carlson-Radvansky & Irwin, 1994), the intrinsic reference frame was dissociated from coincident relative and absolute reference frames by rotating the reference object 90°, as in Figure 1. This resulted in conflicting assignments to vertical spatial relations such as “above.” Significant competition among the dissociated reference frames was observed: Use of one reference frame was more difficult when another indicated a conflicting direction. Another study (Carlson-Radvansky & Logan, 1997) showed that the activation of multiple reference frames is automatic. Despite instructions to use only a specific reference frame, performance was influenced by activation in the noninstructed reference frame.

Address correspondence to Laura Carlson-Radvansky, Department of Psychology, University of Notre Dame, Notre Dame, IN 46556; e-mail: laura.c.radvansky.2@nd.edu.



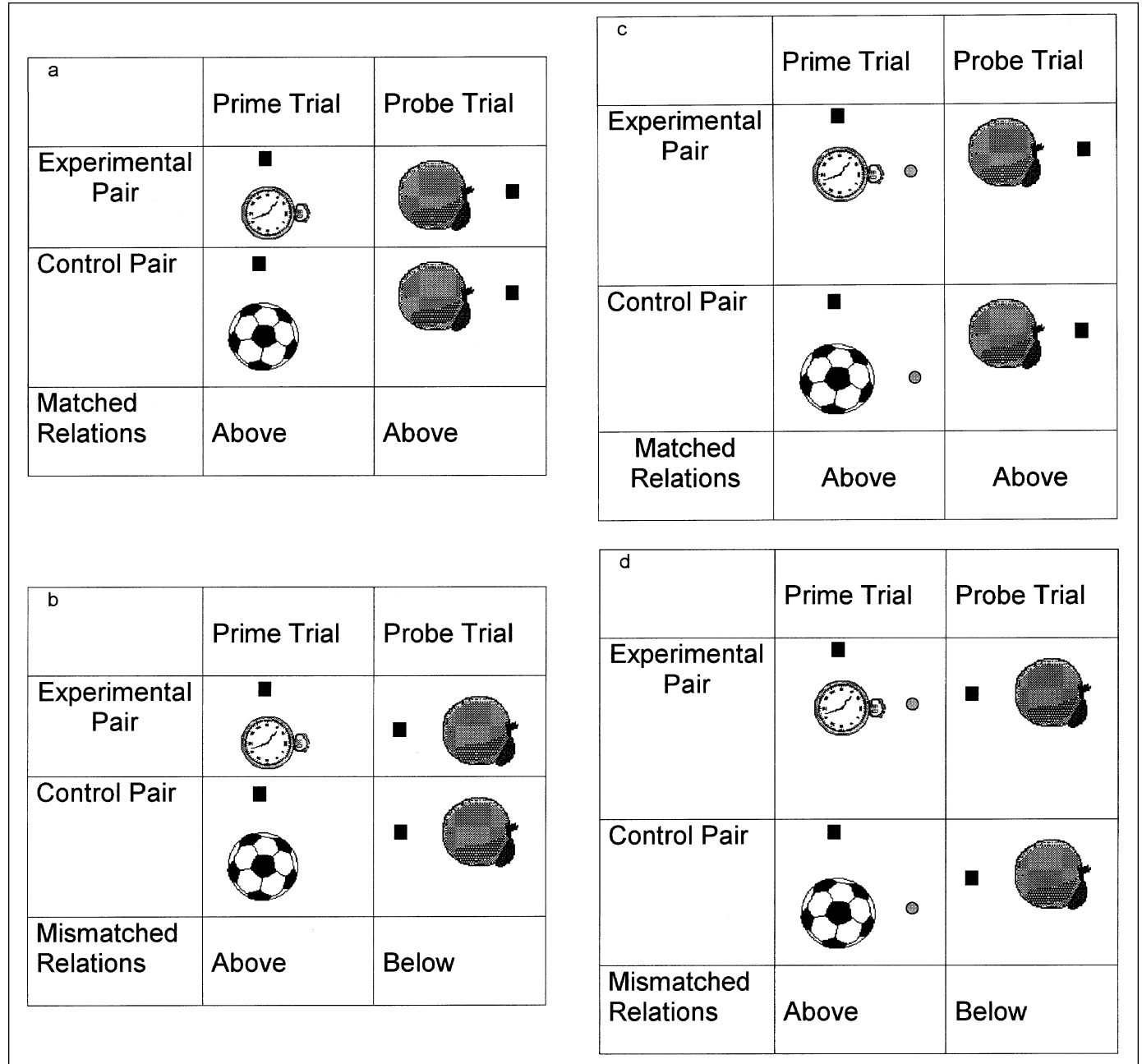
**Fig. 1.** Ambiguity of spatial relations. Box 1 is above the chair according to the absolute reference frame based on gravity, Box 2 is above the chair according to the intrinsic reference frame based on the chair, and Box 3 is above the chair according to the relative reference frame based on the reclining viewer.

## REFERENCE-FRAME SELECTION

The simultaneous activation of multiple reference frames is usually followed by the selection of a single reference frame. For example, in one study (Carlson-Radvansky & Irwin, 1993, Experiment 3), participants selected a single reference frame from among two competing ones on 93% of the trials.

The current experiments explored whether reference-frame selection involves the inhibition of the nonselected reference frames. This idea is borrowed from studies in visual attention that have shown that selection is most efficient when accompanied by an inhibitory mechanism that reduces the availability of the nonintended items (for reviews, see Fox, 1995; May, Kane, & Hasher, 1995). If reference-frame selection involves the inhibition of the other active reference frames, then some cost should be observed in an attempt to use a reference frame on trial  $n$  that was not selected on trial  $n - 1$ . Such a cost is commonly referred to as negative priming (Neill, 1977; Tipper, 1985).

The current experiments assessed negative priming by comparing responses to *experimental* and *control* pairs of prime and probe trials that differed only with respect to the objects used on the prime trials. Consider the pairs of trials shown in Figure 2a. In each box, the small square is the located object and the larger object is the reference object. The task is to judge the acceptability of “above” as a description of the relation between the objects. The experimental prime trial uses a reference object (pocket watch) for which three reference frames are available: coincident relative and absolute reference frames



**Fig. 2.** Experimental and control pairs of prime and probe trials for assessing negative priming in Experiments 1 and 2. Pairs with prime and probe relations that matched and mismatched are shown in (a) and (b), respectively. The same conditions, but with an irrelevant object on the prime trials, are shown in (c) and (d).

and an intrinsic reference frame defined by the sides of the rotated object; such objects are called *triaxial* objects. The control prime trial uses an object (soccer ball) for which only two reference frames are available: the coincident relative and absolute reference frames. Because these objects do not have predefined sides, they cannot define the intrinsic reference frame; such objects are called *biaxial* objects. Placement of the located object (the square) on both prime trials is “above” according to the coincident relative and absolute reference frames. Therefore, on the experimental prime trial, there is a target reference frame (relative-absolute) and a distractor reference frame

(intrinsic); on the control prime trial, there is only a target reference frame. The probe trials in Figure 2a use a rotated triaxial reference object (peach) with the located object placed above it according to the intrinsic reference frame. Thus, the distractor reference frame on the prime trial becomes the target reference frame on the probe trial. If selection uses inhibition, then the intrinsic reference frame will be inhibited on the experimental prime trial but not on the control prime trial. Thus, use of the intrinsic reference frame should be more difficult on a probe trial following an experimental prime trial than on a probe trial following a control prime trial. Across probe trials, the

same reference objects were used, allowing a comparison of identical probe trials as a function of experimental and control prime trials.

Furthermore, inhibition could operate (a) upon all axes of a reference frame, (b) upon a specific axis, or (c) upon a specific endpoint of a specific axis. The current experiments examined the latter two possibilities by including pairs of trials in which the prime and probe relations matched (above-above, below-below; see Fig. 2a) or mismatched (above-below, below-above; see Fig. 2b). We expected that if inhibition operated along the vertical axis, we would observe significant negative priming in both matched and mismatched pairs; however, if only one endpoint were inhibited, we would observe significant negative priming only for the matched pairs.

Because this design relies on participants using the relative and absolute reference frames as well as the intrinsic reference frame across trials, explicit instructions to use these reference frames were given. Baylis and Tipper (1995, cited in Tipper & Milliken, 1996) found that imposing a criterion for responding resulted in more negative priming than allowing participants to decide how to respond.<sup>1</sup>

## EXPERIMENT 1

### Method

#### Participants

Eighteen University of Notre Dame undergraduates participated for course credit.

#### Materials

Each picture contained a central reference object embedded in a gray square that measured 13 cm × 13 cm and appeared on a white field. Sixteen objects were used, eight triaxial (pocket watch, pumpkin, tomato, peach, bear, woman, tree, and bird) and eight biaxial (dartboard, basketball, soccer ball, tennis ball, chain, bicycle wheel, sun, and sand dollar). The objects were similar in shape (roughly circular) and size ( $M = 2.9$  cm in diameter). There were two versions of each picture: In one, the reference object was upright (used in filler trials only); in the other, it was rotated 90° clockwise. Rotation dissociated the intrinsic reference frame from coincident relative and absolute reference frames for triaxial objects, but had no real effect on biaxial objects. Each picture also contained a located object that was a small (3-mm) white square. Across trials, it was placed in one of four locations: relative above, below, left, or right of the reference object from the perspective of the person facing the monitor. The distance from the square to the center of the object was 4.3 cm. A sentence of the form "The square is \_\_\_\_\_ the [reference object]" preceded the picture, with the blank containing the relation "above" or "below" and the name of the reference object appearing in the sentence.

#### Design

There were three types of prime and probe trial pairs: experimental, control, and filler. All pairs were constructed from the following factors:

1. A negative-priming effect resulting from activation within multiple reference frames cannot be due simply to these instructions, because Carlson-Radvansky and Logan (1997) showed that such activation is automatic. Rather, the instructions were used to get participants to select the appropriate reference frame to allow an assessment of negative priming.

spatial term (above or below), orientation of the reference object (upright or rotated), object type (biaxial or triaxial), placement of the located object (above, below, left, or right), and correct answer (yes or no). Experimental and control pairs followed the format displayed in Figure 2, with half of the pairs containing prime and probe relations that matched (e.g., above-above) and half containing relations that mismatched (e.g., above-below). Filler trials were constructed to counterbalance all factors across the experiment. Each participant performed 256 pairs of trials, divided into four blocks of 64, with factors counterbalanced within a block. For each block, there were 8 experimental pairs, 8 control pairs, and 48 filler pairs. From the participant's perspective, there was no indication that the trials formed prime-probe pairs.

### Procedure

A sentence appeared for 1,000 ms on a computer monitor and was replaced with a picture. The task was to determine whether the sentence was an acceptable description of the picture. Participants were told to respond as quickly and accurately as possible by pressing either the "yes" key (?) or the "no" key (z) on the keyboard. Response times were measured from the onset of the picture to the key-press response. Intertrial interval was 1,000 ms.

Participants were told to respond "yes" if the spatial relation in the sentence was correct according to either the intrinsic or the coincident relative and absolute reference frames, and to respond "no" only when the placement was incorrect according to all reference frames. This instruction ensured "yes" responses to both primes and probes for the experimental and control pairs. A picture-identification task and a yes/no response task familiarized participants with the objects and response keys, and eight practice trials were then presented. Feedback was given during practice only, and practice was repeated until fewer than two errors occurred.

### Results and Discussion

Four participants were excluded, 1 because of experimenter error and 3 for not following instructions. Response times less than 100 ms or greater than 5,000 ms were excluded from analysis (less than 1%). A significance level of  $p < .05$  was adopted. Analyses of response times are presented here; analyses of accuracy showed the same pattern but are not reported because of space limitations.

#### Probe trials

Pairs of trials with an incorrect response on the prime (4%) or on the probe (8%) were excluded. The remaining data were submitted to a 2 (prime type: experimental or control) × 2 (prime-probe relation: match or mismatch) repeated measures analysis of variance. Mean response times and accuracy are given in Table 1. There was a main effect of prime type, with responses to probes following experimental primes ( $M = 933$  ms) significantly slower than responses to probes following control primes ( $M = 880$ ),  $F(1, 13) = 5.5$ ,  $MSE = 7,049$ , indicating a negative-priming effect of 53 ms. There was also a main effect of prime-probe relation, with matched relations ( $M = 879$  ms) significantly faster than mismatched relations ( $M = 934$  ms),  $F(1, 13) = 5.4$ ,  $MSE = 7,755$ . The interaction was not significant,  $F < 1$ . As much negative priming was observed when the relations mismatched ( $M = 49$  ms) as when they matched ( $M = 56$  ms), indicating that negative priming operates at least along the whole axis of the reference frame rather than being restricted to a particular endpoint.

**Table 1.** Mean correct response times (ms) and percentage correct (in parentheses) for the experimental and control probe trials in Experiments 1 and 2

Prime-probe relation	Prime type		
	Experimental	Control	Negative priming
Experiment 1: Irrelevant object absent			
Match	907 (94)	851 (95)	56 (-1)
Mismatch	958 (89)	909 (92)	49 (-3)
Experiment 2: Irrelevant object absent			
Match	981 (95)	853 (100)	128 (-5)
Mismatch	989 (96)	925 (98)	64 (-2)
Experiment 2: Irrelevant object present			
Match	946 (97)	935 (97)	11 (0)
Mismatch	1,005 (94)	939 (94)	66 (0)

*Note.* Negative priming was calculated by subtracting the data for the control trials from the data for the experimental trials.

### Prime trials

Mean response times on prime trials were also analyzed as a function of prime type and prime-probe relation. There was a main effect of prime type, with responses to experimental primes ( $M = 973$  ms) significantly slower than responses to control primes ( $M = 768$  ms),  $F(1, 13) = 41.3$ ,  $MSE = 14,319$ . The effect of prime-probe relation was marginally significant ( $p = .09$ ), but not interpretable because the matched or mismatched designation does not apply to prime trials by themselves. The interaction was not significant,  $F < 1$ .

The effect of prime type is not surprising, given that rotated objects (in the experimental prime trials) take longer to recognize than upright objects (in the control prime trials) (Carlson-Radvansky & Irwin, 1994; Maki, 1986; McMullen & Jolicoeur, 1990). Indeed, many researchers have described such orientation effects using reference frames (e.g., McMullen & Jolicoeur, 1990; Robertson, Palmer, & Gomez, 1987; Rock, 1973). This effect supports the idea that the intrinsic reference frame was active although not selected on experimental prime trials. Comparison of prime trials when the reference objects were all upright (as on filler trials) revealed no difference between triaxial and biaxial objects ( $M_s = 763$  ms and 770 ms, respectively),  $t(13) < 1$ .

### Summary

Experiment 1 demonstrated significant negative priming that encompassed both endpoints of the axis of a reference frame, suggesting that inhibition assists in reference-frame selection.

## EXPERIMENT 2

In Experiment 2, we examined how reference-frame selection is affected when participants also need to select the located object. We were motivated by the observation that locating objects in the real world often involves selecting one object from among many objects. Also, the need to select an object is the standard task in most negative-priming experiments (see Fox, 1995; May et al., 1995). Accordingly,

on some experimental and control prime trials, we placed an irrelevant object so that it was correct with respect to the nonselected reference frame.<sup>2</sup> Figures 2c and 2d illustrate the conditions for trials with matched and mismatched prime-probe relations, respectively. Participants were told that the square was the located object, and that the circle was an irrelevant object that would appear on some trials and should be ignored. For the experimental prime trials, the irrelevant object was placed correctly with respect to the to-be-inhibited (intrinsic) reference frame.

The question was whether object selection would influence reference-frame selection. Experiment 1 demonstrated that the presence of an irrelevant object was not necessary for significant inhibition of the nonselected reference frame (see also Carlson-Radvansky & Irwin, 1994; Carlson-Radvansky & Logan, 1997). However, it is possible that placing an irrelevant object with respect to the nonselected frame serves to boost activation in that frame; this would require a concomitant increase in the amount of inhibition required, resulting in more negative priming. We reasoned that if this were the case, this increase in negative priming would be observed on both matched and mismatched trials, given that in Experiment 1, inhibition operated along the axis of a reference frame rather than on a specific endpoint.

In contrast, it is possible that object selection is largely independent of reference-frame selection. According to Logan and Sadler (1996; see also Carlson-Radvansky & Logan, 1997), search for and selection of the located object takes place after a reference frame has been selected. This suggests that any effect due to object selection may be additive with any effect due to reference-frame selection. We reasoned that such an effect would operate only at the location of the irrelevant object, and thus be observed only on matched trials because only on such trials was the located object on the probe trials placed where the irrelevant object was on the prime trials (see Fig. 2c). Thus, if this interpretation were correct, there would be differential negative

2. We thank an anonymous reviewer for this suggestion.

priming across matched and mismatched trials in the presence of an irrelevant object.

## Method

### Participants

Thirty-one University of Notre Dame undergraduates participated for course credit.

### Materials and design

The pictures from Experiment 1 were used. On half of the trials, an irrelevant object (a red circle with a 3-mm diameter) appeared, along with the located object (white square). For the experimental and control pairs, the irrelevant object was always placed on the prime trial in accordance with the nonselected (intrinsic) reference frame. For the filler pairs, the irrelevant object was placed on both prime and probe trials and in all possible locations so that it appeared in each location and on prime and probe trials an equal number of times across all trials. Each participant performed 256 pairs of trials; on half the irrelevant object was present, and on half it was absent. The irrelevant-object-absent trials directly replicated Experiment 1. The trials were divided into four blocks of 64 pairs, with trials with and without the irrelevant object randomly intermixed; all factors were counterbalanced within a block.

### Procedure

The procedure from Experiment 1 was modified to include the instruction to base judgments on the placement of the white square around the reference object, and to ignore the red circle when it appeared. Practice included trials with the irrelevant object present and absent.

## Results and Discussion

Three participants were excluded for failing to follow instructions. Response times less than 100 ms or greater than 5,000 ms were excluded (less than 1%). Analyses on the accuracy data showed the same general pattern as the analyses on response times.

### Probe trials

Experimental and control pairs with incorrect responses on the prime (4%) or on the probe (4%) were excluded. The remaining data were submitted to a 2 (prime type: experimental or control)  $\times$  2 (prime-probe relation: match or mismatch)  $\times$  2 (irrelevant object: present or absent on the prime trial) repeated measures analysis of variance. Mean response times and accuracy are given in Table 1. There was a significant main effect of prime type, with responses to probes following experimental primes ( $M = 981$  ms) slower than responses to probes following control primes ( $M = 913$ ),  $F(1, 27) = 4.8$ ,  $MSE = 52,495$ , indicating a negative-priming effect of 68 ms. There was also a significant main effect of prime-probe relation, with matched relations ( $M = 929$  ms) significantly faster than mismatched relations ( $M = 965$  ms),  $F(1, 27) = 4.3$ ,  $MSE = 16,844$ . There was no interaction between prime type and prime-probe relation, indicating as much negative priming when the prime-probe relations mismatched ( $M = 65$  ms) as when they matched ( $M = 70$  ms),  $F < 1$ . These data replicate the results of Experiment 1.

There was no main effect of irrelevant object ( $F < 1$ ), and this factor did not interact significantly with the other factors individually

( $F_s < 1.5$ ,  $p_s > .23$ ), although the three-way interaction approached significance,  $F(1, 27) = 2.7$ ,  $MSE = 18,406$ ,  $p = .11$ . Given the wide range of negative-priming effects (see Table 1), we explored this interaction further by calculating a 95% confidence interval using the error term for the interaction (Fisher, 1966; Loftus & Masson, 1994); a critical difference of 62 ms was required for significance. When the irrelevant object was absent (as in Experiment 1), there was significant negative priming for the matched trials (128 ms) and mismatched trials (64 ms).<sup>3</sup> However, when the irrelevant object was present, negative priming was significant for mismatched trials (66 ms) but not for matched trials (11 ms).

We interpret the elimination of negative priming for the matched trials as the result of combined effects of reference-frame selection and object selection. In terms of reference-frame selection, the mismatched trials indicate that the axis was inhibited. Thus, the object-selection effect must have been facilitatory in order for the negative-priming effect to disappear. There are two possible reasons for a facilitation effect. First, the object-selection task was very easy and may not have invoked an inhibitory mechanism. Second, inhibition may have been applied to the irrelevant object, but been restricted to the color and shape of the object, features that were relevant to behavioral goals (Tipper, Weaver, & Houghton, 1994). Both possibilities would leave the irrelevant object's location activated, which would offset any inhibition applied during reference-frame selection.

### Prime trials

Mean response times were analyzed as a function of prime type, prime-probe relation, and presence or absence of the irrelevant object using a 2  $\times$  2  $\times$  2 repeated measures analysis of variance. There was a significant effect of prime type, with responses on experimental prime trials ( $M = 1,011$  ms) slower than responses on control prime trials ( $M = 837$  ms),  $F(1, 27) = 21.3$ ,  $MSE = 79,516$ . This effect was presumably due to the change in orientation of the reference object, because comparison of prime trials on which the reference objects were all upright revealed no difference between triaxial and biaxial objects ( $M_s = 813$  ms and 797 ms, respectively),  $t(27) < 1$ . There was a main effect of presence of the irrelevant object, with irrelevant-object-present trials ( $M = 947$  ms) significantly slower than irrelevant-object-absent trials ( $M = 901$  ms),  $F(1, 27) = 4.1$ ,  $MSE = 29,712$ . This finding demonstrates that participants were unable to completely ignore the irrelevant object on the prime trials, and indicates the need for object selection. There were no other effects, all  $F_s < 1$ .

### Summary

Experiment 2 replicated Experiment 1 by demonstrating significant negative priming that encompassed both endpoints of the axis of a reference frame. In addition, reference-frame selection was found to be largely independent of object selection, a process invoked by the presence of an irrelevant object in the display. Specifically, on the irrelevant-target-present trials, there was significant negative priming on mismatched trials, but an absence of negative priming on matched trials. We interpret the absence of negative priming on matched trials as resulting from a combination of inhibition due to reference-frame selection and activation due to object selection.

3. Negative priming did not differ across these conditions,  $F(1, 27) = 1.5$ ,  $MSE = 18,915$ ,  $p = .23$ .

## GENERAL DISCUSSION

Experiments 1 and 2 both showed significant negative priming of the axis of a reference frame on trial  $n$  when the reference frame was not selected for use on trial  $n - 1$ . Our interpretation of these results is that inhibition assists in the selection of one reference frame from a set of simultaneously activated reference frames (Carlson-Radvansky & Irwin, 1994; Carlson-Radvansky & Logan, 1997) by suppressing the relevant axis of the nonselected reference frame. The finding that inhibition is applied to the axis rather than the relevant endpoint suggests that axes and endpoints may be separate parameters of reference frames (Logan & Sadler, 1996). Further research needs to address whether inhibition is restricted to a particular relevant axis (e.g., vertical) or whether it operates on all axes of the reference frame.

One possible consequence of the use of inhibition in reference-frame selection is the consistent use of a reference frame across trials. For example, people seem to have preferences for using particular reference frames for particular spatial relations (Carlson-Radvansky & Logan, 1997). Moreover, participants who are working together in a spatial task tend to coordinate their use of reference frames (Schober, 1993). Future work should determine whether negative priming varies as a function of the type of reference frame to be inhibited, and how this is related to preference for use.

Experiment 2 also examined the relationship between reference-frame selection and object selection. Including an irrelevant object on prime displays resulted in no negative priming at the location of the irrelevant object on probe displays. This finding suggests that object selection resulted in facilitation that offset the inhibition applied during reference-frame selection. Future work should address whether increased negative priming could also be observed at this location with a more difficult object-selection task. More generally, these results demonstrate two points about reference-frame selection: First, the presence of an irrelevant object is not necessary for inhibition of the nonselected reference frame, because significant negative priming was observed on trials without the irrelevant object. Second, the presence of an irrelevant object does not change the amount of inhibition applied to the axis of the reference frame. Negative priming for mismatched trials with an irrelevant object was similar to the negative priming for mismatched trials without an irrelevant object.

Finally, we have interpreted negative priming as the product of an inhibitory mechanism whose deployment is flexible and goal related (Milliken, Tipper, & Bruce, 1994; Tipper et al., 1994). It should be noted, however, that an interpretation of negative priming based on episodic trace retrieval (Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992) could also explain our results. Selection of the intrinsic frame on probe trials would cause the implicit and automatic retrieval of previous trials involving the intrinsic reference frame, including the experimental prime trials. On these prime trials, the intrinsic reference frame was not selected, and would therefore have had a "do not use" tag associated with it. However, on probe trials, this reference frame would have been selected, and it would therefore have had a "use" tag associated with it. This conflict between tags could be responsible for the slower responses on the probe trials following experimental primes relative to the probe trials following control primes that did not involve the intrinsic reference frame.

Regardless of which interpretation is correct, we believe our findings are important because they offer one of the few demonstrations of

negative priming to an abstract construct (a reference frame) that is never physically presented. (Negative priming to abstract constructs has also been reported for, e.g., semantic meanings: Tipper & Driver, 1988; actions: Tipper, Lortie, & Baylis, 1992; and situation models: Radvansky, 1998).

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