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Encoding direction when interpreting proximal terms

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The location of an object is often described by spatially relating it to a known landmark. The spatial terms used in such descriptions can provide various types of information. For example, projective terms such as *above* indicate direction but not distance, whereas proximal terms such as *near* indicate distance but not direction. Previous research has demonstrated that information not explicitly specified by projective prepositions (i.e., distance) is also encoded during the interpretation of these terms. Using a sentence-picture verification task, we examined whether direction is similarly encoded during the apprehension of proximal terms, examining both spatial prepositions (e.g., *near*) and motion verbs (e.g., *approach*). Results suggest that interpreting proximal terms involves encoding direction when such information facilitates locating the target.

Imagine that you are waiting for a friend in a new restaurant by the park. Your cell phone rings, and your friend tells you that she is at the park, but cannot find the restaurant. There are many different descriptions that you could provide to assist your friend in finding the correct eatery. One helpful description would locate the restaurant relative to a reference object that is either known to your friend or is easily identifiable (Talmy, 1983). For example, you could respond with either of the spatial descriptions in (1–2):

(1) The restaurant is to the left of the fountain.
(2) The restaurant is near the fountain.

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In order to find the restaurant based on these descriptions, your friend would need to identify and locate the fountain; define a region of space surrounding the fountain that corresponds to the spatial term in the description; and search this space for the restaurant (Logan & Sadler, 1996). Of central interest in the current paper is the manner in which the space around the fountain is defined as a function of the different spatial relations (*left*, *near*) used in descriptions (1) and (2).

DEFINING SPACE AROUND REFERENCE OBJECTS

Spatial terms such as *left* and *near* are assigned to space around a reference object through the use of a reference frame. Reference frames are typically conceptualised as a set of axes that define space in a three-dimensional Euclidean framework (for an excellent summary of reference frames across various domains, see Levinson, 1996). According to the framework specified by Logan and Sadler (1996), reference frames are variable representations with a number of parameters that can be flexibly set; these include an origin, orientation, direction, and distance.[1] Origin corresponds to the place within the scene at which the reference frame is imposed; for the current experiments, the origin is on the reference object. Orientation corresponds to the assignment of the axes to the vertical (above/below) and horizontal (front/back and left/right) dimensions. Endpoint corresponds to the direction assigned to each axis (i.e., the left and right endpoints on the left/right axis). Distance corresponds to space between the reference object and the target.

The contrast between the spatial descriptions in (1) and (2) reflects a difference in emphasis in the parameters that define the space around the reference object. In (1), the spatial term *left* highlights the direction of the restaurant relative to the fountain, whereas in (2) the spatial term *near* highlights the distance of the restaurant relative to the fountain. Indeed, spatial prepositions have been classified upon this basis (Coventry & Garrod, 2004), with terms specifying direction labelled *projective*, and terms specifying distance labelled *proximal*.

Such classification has led to the suggestion that during apprehension only the parameters corresponding to information specified by the spatial term are set (Logan & Sadler, 1996). For example, interpreting *near* would only involve setting the distance parameter, but not the orientation and direction parameters; in contrast, interpreting *left* would involve setting the

[1] Logan and Sadler (1996) originally labelled this parameter *scale*. However, as Carlson and van Deman (2004) point out, the more general label of *distance* may be more appropriate because it does not carry the additional assumption that the distance be parsed into equally spaced increments. Hence, we refer to this parameter as *distance* in the current paper.

orientation and direction parameters, but not the distance parameter. In support of this idea, Logan and Sadler (1996) asked participants to draw an 'X' in various spatial relations around a square. For proximal relations denoted by the terms *near* and *far*, participants consistently placed the X at particular distances but with no consistent direction. In contrast, for projective relations denoted by *left* and *above*, participants consistently placed the X at particular directions, but with no consistent distance.

ENCODING DISTANCE WHEN INTERPRETING PROJECTIVE TERMS

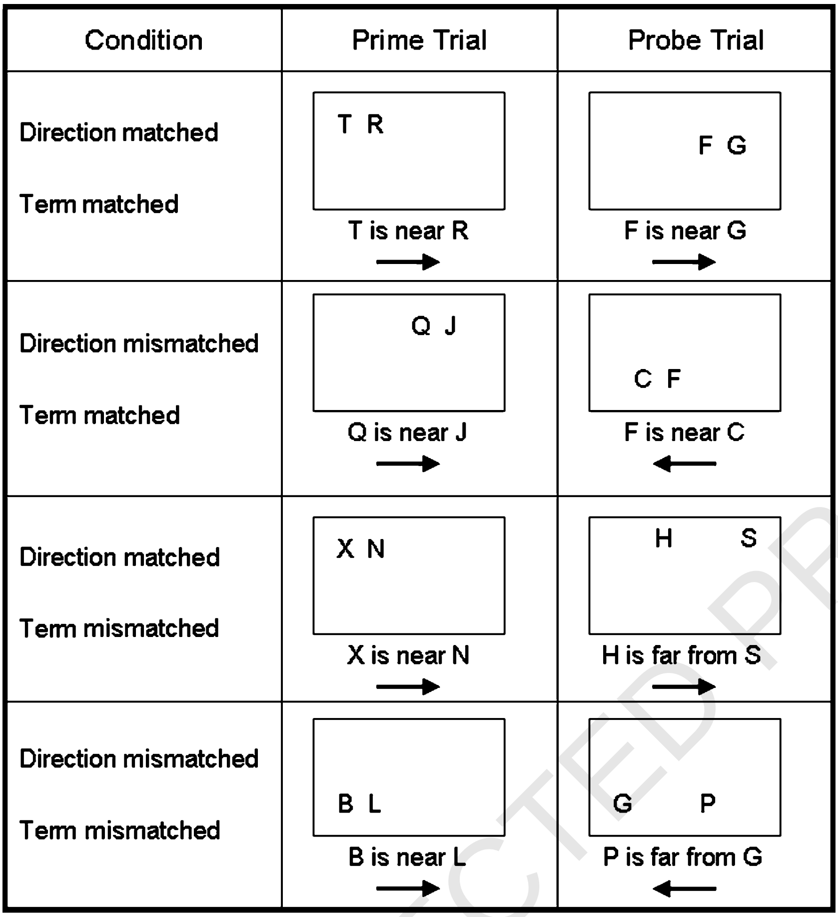
Recently, Carlson and Van Deman (2004) argued against the assumption that only information specified by the spatial term is encoded during its interpretation. They observed that although a given spatial term may convey only a given type of information, other types of information may nonetheless be available. As distance and direction are considered primary means for specifying location (Landau & Jackendoff, 1993; Vorwerg, 2003), encoding both types of information may be helpful for subsequent actions on the target. For example, assume that you respond to your friend's inquiry about the restaurant using the spatial description in (1). Once she locates the restaurant relative to the fountain, she knows not only its direction (left, as specified by the description) but also its distance (as provided by the scene). Indeed, she can use such distance information to facilitate her walk to the restaurant, in terms of determining her pace, estimating her time of arrival, and so on.

As a test of this idea, Carlson and Van Deman (2004) examined projective prepositions such as *left* and *above*, assessing whether not only direction (as conveyed by the term) but also distance (as provided in the display) would be encoded during their interpretation. Participants performed a speeded sentence-picture verification task, in which they assessed whether a sentence of the form 'LETTER is above/below/left/right LETTER') was an accurate description of a display containing two letters. On trials requiring *yes* responses, the letters in the display were placed in the correct spatial configuration with respect to the spatial term in the sentence. In addition, the distance between the letters within the display could be short or long. Note that the spatial term could be correctly applied to the configuration regardless of distance if the configuration was correct; this renders the distance information largely irrelevant for the verification decision. The critical question then was whether such distance information would nonetheless be encoded. To assess this, unbeknownst to participants, the trial stream was configured into prime/probe pairs, and the critical manipulation was whether the distance between the letters in the displays within a pair matched or mismatched. The logic was that if distance were encoded during the processing of these spatial terms, then the distance parameter would be set to a particular value on the prime trial. If the same distance then appeared on the probe trial, its encoding would be facilitated because the value would remain the same, relative to when the distance mismatched and a new value would need to be encoded.

The critical finding was facilitation on probe trials when the distance matched within a pair of trials, with this facilitation occurring regardless of whether the spatial terms used on the prime and probe trials were the same (i.e., *above* on prime and *above* on probe) or were different (i.e., *above* on prime and *left* on probe). Importantly, this facilitation was only observed when the task involved verifying the spatial relation between the letters. When the same displays were used but the task was changed to an identity verification task or size judgement task, the facilitation due to distance being matched across prime and probe trials was not observed. This suggests that distance information was not always encoded as a function of attending to the displays; rather, distance was only encoded in the context of interpreting spatial terms, suggesting that such information was helpful in locating the target. More generally, this suggests that the parameters of a reference frame that are set during the interpretation of a spatial term are not limited to those that correspond to the information specified by the term.

ENCODING DIRECTION WHEN INTERPRETING PROXIMAL TERMS

The goal of the current study was to test the generalisability of the idea that the interpretation of a spatial term involves setting not only the parameters that correspond to information specified by the spatial term, but also information available in the display that may assist in locating the target. To assess this, we applied the paradigm developed by Carlson and Van Deman (2004) to the class of proximal spatial terms that specify distance but not direction. Given that distance and direction are both valuable dimensions in specifying location (Landau & Jackendoff, 1993; Vorwerg, 2003), similar facilitation should be observed in the interpretation of proximal terms across prime/probe pairs when the direction between the letters is matched versus mismatched. Sample displays illustrating the direction manipulation across prime and probe pairs are shown in Figure 1. Across types of pairs, the spatial term across prime and probe trials can be matched or mismatched (near/near, far/far, near/far, far/near, and the direction from target to reference object can be matched or mismatched). Specifically, Row 1 shows a pair of prime and probe trials for which the spatial term is matched (near) and the direction is matched (as indicated by the arrows). If direction is



Note. Arrows indicate the direction from target to reference object, and are included only to help define the various conditions. The arrows did not appear in the experimental displays.

Figure 1. Sample displays illustrating the factors of term correspondence and direction correspondence for prime and probe trials.

encoded on the prime trials, then interpreting the same spatial term on probe trials should be facilitated when the direction is the same. This would be indicated by a positive difference, computed by subtracting the probe response time from the prime response time. Note, however, that because this condition also has the same spatial term between prime and probe trial, a positive difference may also reflect a benefit due to repeating the spatial term. To assess this, Row 2 shows a condition in which the spatial term is matched but the direction is mismatched. This condition offers a pure estimate of the benefit due to repeating the spatial term in the absence of having direction matched. If direction is encoded, then one would expect greater facilitation for the conditions in Row 1 in which direction is matched and term is matched than for the conditions in Row 2 in which only the term is matched. Rows 3 and 4 show conditions in which the terms are mismatched across prime and probe trials, and direction is either matched or mismatched. These conditions enable us to assess whether the direction parameter can be set independently of the spatial term being processed. For projective spatial terms, Carlson and Van Deman (2004) observed facilitation due to distance being matched across prime and probe trials that did not depend upon the spatial term being matched across prime and probe trials. The conditions in Row 3 allow us to assess whether such independence would also hold for proximal terms. If the direction parameter can be set for one term and applied to another term, then one would expect to see facilitation for the conditions in Row 3 in which the direction matches but term mismatches. If, however, the setting of the direction parameter is tied to the particular spatial term, then no facilitation should be observed when the terms mismatch across prime and probe trials as in Row 3. Finally, Row 4 provides a baseline when neither direction nor term match across prime and probe trials.

THE CURRENT STUDY

Across four experiments we compared response time differences across sets of conditions as in Figure 1 to assess whether direction information is encoded during the interpretation of proximal terms. Specifically, Experiment 1 examined whether direction is encoded during the interpretation of the proximal spatial prepositions *near* and *far*. Experiment 2 demonstrated that encoding direction depended upon interpreting the spatial terms, and was not simply due to attending to the displays. Experiments 3 and 4 extended the results of Experiment 1 by examining whether direction is encoded during the interpretation of the proximal spatial verbs *approach* and *avoid*. The specific motivation and predictions for Experiments 2–4 are provided within the individual experiments.

Experiment 1: *Near* and *far*

Method

Participants. Participants were 96 University of Notre Dame undergraduates recruited from the Psychology Department research subject pool.

All participants were naïve with respect to the experimental hypotheses and received partial course credit for their participation. None participated in any other experiment reported in this manuscript.

Stimuli. Sentences of the form ‘LETTER is *near*/*far from* LETTER’ written in 18 point Courier New font were centred on 16-inch monitors configured at 640 × 480 resolution. Letters were selected randomly from all consonants, with the restriction that the same letter could not appear more than once within a prime/probe pair. Picture displays contained two horizontally aligned letters (6 × 9 mm) placed within an invisible 10 × 10 grid (330 × 254 mm). Letter placement was randomly selected with the constraint that on *near* trials, letters appeared in adjacent cells (2.2° of visual angle at a viewing distance of approximately 65 cm), and on *far* trials, letters were separated by three intervening cells (9.18° of visual angle). Letters never occurred in the same location across critical prime/probe trials; on filler trials, letters appeared in the same location across consecutive trials on average less than once per participant. Note also that different letters appeared within the displays across prime/probe trials. Thus, any facilitation observed on probe trials relative to prime trials could not be attributed to letter identity or placement, but rather to direction correspondence: whether the direction matched or mismatched across prime and probe displays and term correspondence; whether the spatial term matched or mismatched across prime/probe displays. The factor of direction correspondence enabled us to assess whether maintaining the direction from prime to probe trial (direction matched) facilitated the interpretation of the probe trial, relative to when the direction was not maintained from prime to probe trial (direction mismatched). The factor of term correspondence enabled us to assess whether direction is encoded with respect to a specific spatial term, in which case facilitation would only be observed when direction matched and term matched, or whether direction was encoded independently of term, in which case facilitation would be observed when direction matched versus mismatched regardless of term correspondence.

Design. Participants completed 256 prime/probe trial pairs, divided into four blocks of 64 pairs, with breaks between blocks. Each block contained 16 critical trial pairs in which the sentence was always an accurate description of the display on both prime and probe trials (yes/yes pairs). These trials were constructed from the following factors: 2 (spatial term on prime trial: *near* vs. *far*) × 2 (prime/probe term correspondence: matched vs. mismatched) × 2 (direction from target to reference object on the prime: T → R vs. R ← T) × 2 (prime/probe direction correspondence: matched vs. mismatched). Each block also contained 48 filler trial pairs (16 in which the sentence was not an accurate description of the display on both trials (no/no), 16 in which the sentence was accurate for the first trial but not accurate for the second trial (yes/no) and 16 in which the sentence was not accurate for the first trial but was accurate for the second trial (no/yes)). There were three types of 'no' trials that were balanced within each type of filler trial: (1) the letters in the display did not match the letters in the sentence; (2) the spatial relation between the letters in the display did not match the relation in the sentence; (3) neither the letters nor the spatial relation in the display matched those of the sentence. Finally, each set of filler trial pairs were constructed from the same factors as the critical trials (2 (term on prime) × 2 (prime/probe term correspondence) × 2 (direction on prime) × 2 (prime/probe direction correspondence).

Procedure. A sentence of the form 'LETTER is *near*/*far from* LETTER' was shown for 2000 ms followed by a picture display containing two letters. Participants responded as quickly and accurately as possible whether the sentence was an accurate description of the display by pressing the 'z' or the '/?' keys, with 'yes' and 'no' key assignment counterbalanced across participants. The display remained on the screen until a response was initiated, with response time measured from display onset until response.

Results and discussion

Pairs of prime/probe trials were deemed unacceptable and removed if response time on the prime or probe trial was < 300 ms or > 3000 ms, and/or if there was an error on either the prime or probe trial. Using these criteria, data from 19 participants were discarded because they had $> 30\%$ unacceptable trials. For the remaining 77 participants, 86% of their critical trials were acceptable; the trimmed data for these participants were due to errors on the prime trial (4%), errors on probe trial (8%), errors on both prime and probe trials ($< 1\%$), response time outside of range on prime trials ($< 1\%$), response time outside of range on probe trials ($< 1\%$), response time outside of range on both primes and probes ($< 1\%$) or both error and response time outside of range ($< 1\%$).

The data of interest are effects of maintaining term and direction for critical acceptable prime/probe trials. Accordingly, separate 2 (prime/probe term correspondence: matched vs. mismatched) × 2 (prime/probe direction correspondence: matched vs. mismatched) repeated measures ANOVA analyses were conducted on prime and probe response times and differences (prime response time – probe response time), collapsing across the particular term (near, far) and direction (T→R, R←T) for increased power. For all analyses, a significance level of $p = .05$ was adopted, unless otherwise indicated.

Prime and probe responses times. Mean prime and probe response times and standard errors as a function of direction correspondence and term correspondence are provided in Table 1. For prime response times, there were no significant effects, although there was a trend for faster responses for prime trials followed by mismatched term probes ($M = 941$ ms) than followed by matched term probes ($M = 958$ ms), $F(1, 76) = 3.6$, $0^2 = .05$, $p = .06$, and a trend for faster responses for prime trials followed by matched direction probes ($M = 941$ ms) than followed by mismatched direction probes ($M = 959$ ms), $F(1, 76) = 3.3$, $0^2 = .04$, $p = .07$. These factors are not relevant to the prime trials, as they are defined as a function of the correspondence between prime and probe. That is, when processing the prime trial, whether the subsequent probe trial is matched or mismatched on a particular dimension is irrelevant. Nonetheless, any differential processing on prime trials may impact the processing on the probe trials, and is accordingly taken into account within the analyses focusing on the differences.

For probe response times, there was a significant effect of direction correspondence, with probe trials with matched prime/probe direction significantly faster ($M = 912$ ms) than probe trials with mismatched prime/probe direction ($M = 981$ ms), $F(1, 76) = 42.6$, $0^2 = .359$. The main effect of term correspondence ($F < 1$) and the interaction between term correspon-

TABLE 1
Mean prime and probe response times as a function of prime/probe term (Experiments 1, 3, 4) or distance (Experiment 2) correspondence, and prime/probe direction correspondence. Standard error of the mean is listed in parentheses.

	Prime trials		*Probe trials*	
Correspondence	*Direction matched*	*Correspondence mismatched*	*Direction matched*	*Correspondence mismatched*
Experiment 1: Near/far				
Term-matched	951 (21)	965 (21)	908 (20)	989 (22)
Term-mismatched	930 (20)	953 (21)	915 (20)	973 (19)
Experiment 2: And				
Distance-matched	788 (14)	811 (16)	777 (17)	793 (16)
Distance-mismatched	796 (15)	796 (15)	789 (17)	802 (15)
Experiment 3: Approach/avoid (static)				
Term-matched	1001 (27)	975 (22)	903 (24)	933 (23)
Term-mismatched	986 (24)	983 (24)	1017 (28)	1013 (25)
Experiment 4: Approach/avoid (animated)				
Distance-matched	953 (42)	941 (40)	852 (38)	876 (36)
Distance-mismatched	904 (38)	949 (38)	976 (44)	935 (38)

dence and direction correspondence ($F < 1.6$, $p > .22$) were not significant. The effect of direction correspondence offers an initial suggestion that the probe trials were facilitated when the direction was maintained from the prime trial. To more directly assess this while taking into account any differential processing on the prime trials, we next examine the effects of term correspondence and direction correspondence on the differences between prime and probe trials.

Differences. Mean differences (prime response time – probe response time) are graphed as a function of direction correspondence and term correspondence in Figure 2, Panel A; error bars are standard errors. There was a main effect of direction correspondence, such that there was significantly more facilitation when the direction matched across prime and probe trials ($M = 29$ ms) than when it mismatched ($M = -22$ ms), $F(1, 76) = 13.9$, $0^2 = .154$. The effect of term correspondence and the interaction between term correspondence and direction correspondence were not significant, $F\text{s} < 1$. As indicated by the asterisk (*) in Figure 2A, there was a significant facilitation (when tested against 0) only in the term-matched/direction-matched condition, $t(76) = 3.7$; for the other conditions, $t\text{s} < 1.6$, $p\text{s} > .18$. Moreover, comparing the two conditions in which the term matched (cf Rows 1 and 2 in Figure 1), the benefit when the direction matched was significantly greater than the cost observed when direction mismatched, $t(76) = 3.8$, as indicated by the asterisk (*) and bracket connecting these two conditions in Figure 2A.

These results indicate that direction was encoded on the prime trial, such that when the same value could be used from the prime trial to the probe trial, there was facilitation. However, such benefit was restricted to conditions in which the terms matched; this might imply that the encoded direction was tied to the particular spatial term rather than being generally available. This interpretation should be made with some caution, however, given that the term mismatched conditions showed the same general pattern (although without significant effects). The idea that the encoding of direction may be restricted to a particular spatial term is interesting, given that Carlson and Van Deman (2004) observed a general distance effect in which encoding a distance with respect to one spatial term (e.g., *left* on prime) resulted in facilitation when the distance matched but a different spatial term occurred on the subsequent trial (e.g., *above* on probe). The possible restriction of the encoding of direction with respect to a particular term will be further explored with proximal motion verbs in Experiments 3 and 4.

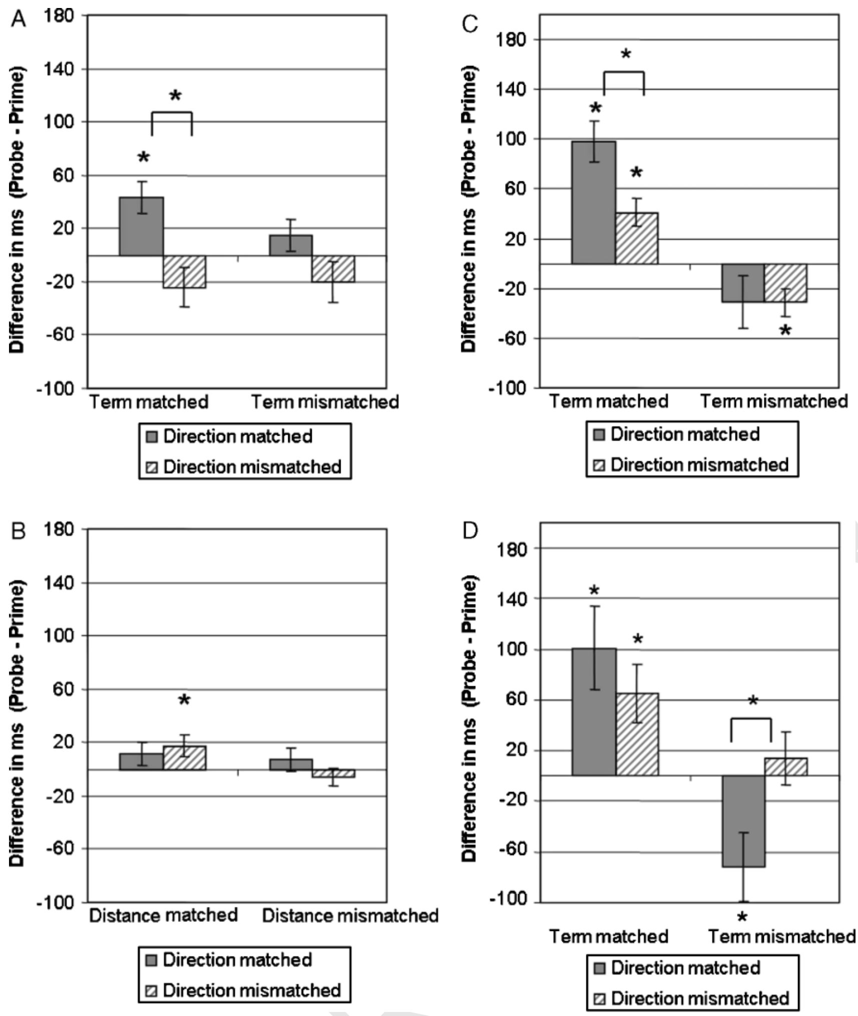


Figure 2. Difference scores (prime response time – probe response time) in ms as a function of term correspondence and direction (Experiments 1, 3, and 4) or distance (Experiment 2) correspondence for Experiment 1–4 (panels A–D, respectively); error bars are standard error of the mean. The presence of an asterisk (*) above a bar indicates that that condition is significantly different from 0; the presence of an asterisk (*) above a bracket that connects two conditions indicates that these conditions differ significantly, all ps $<.05$.

Experiment 2: 'And' task

The results of Experiment 1 suggest that direction is encoded during the interpretation of the proximal spatial prepositions *near* and *far*. Together with the results from Carlson and Van Deman (2004) showing that distance information was encoded during the processing of projective spatial prepositions that specify direction, the findings from Experiment 1 suggest that the parameters of a reference frame that are used during the interpretation of spatial terms do not solely depend upon information explicitly specified by the spatial term. In Experiment 1, even though direction was not specified by *near* and *far*, this information was nonetheless encoded for subsequent use. Carlson and Van Deman argued that such additional information might be encoded because it would be relevant for subsequent action on the target. That is, if the purpose of a spatial description is to specify the location of target, knowing both direction and distance may be particularly useful (Carlson & Van Deman, 2004; Landau & Jackendoff, 1993; Vorwerg, 2003). If this is correct, then one might expect that such information would not be encoded when the task does not focus on locating objects. Indeed, Carlson and Van Deman (2004) showed that distance information was not encoded for projective terms when the same displays were used in the context of an identity task. In Experiment 2, we pursued the same logic, and assessed whether direction information would be encoded when participants viewed the same displays as in Experiment 1 within a task in which they simply had to verify whether two letters appeared in the display (i.e., sentences were of the form '*A and B*' vs. '*A near B*' in Experiment 1). Because locating the target is no longer relevant to the task, one should no longer see evidence of encoding direction when verifying identity in this 'and' version of this task.

It is important to note that the processing of identity within the 'and' task is likely a component of the processing that is performed while interpreting spatial terms as well. Indeed, on filler trials in Experiment 1, participants had to respond 'no' regardless of the correctness of the spatial relation between the letters if the identity of the letters did not match between sentence and display. Thus, participants were presumably processing identity in Experiment 1, much as they need to for the task for Experiment 2. In this sense, the allocation of attention from one object to another is equated across the two types of tasks (Logan, 1995). Indeed, Carlson and Van Deman (2004) argue that the shifting of attention from one object to another provides a good mechanism for computing distance information, given evidence that attention is required for interpreting spatial relations (Logan, 1995). Thus, the critical difference between Experiments 1 and 2 is not in the way in which the attention is allocated across the displays. Indeed, for both tasks it is presumed that the shift of attention offers a means of computing distance and direction information. Rather, it is the usefulness of such information for the task that dictates whether or not the information is subsequently retained. When such information is useful, as in Experiment 1 in which a target is located, it should be retained and hence influence subsequent processing; however, when such information is not useful, as in Experiment 2 in which only identity is relevant, then such information should not be retained and hence show no influence on subsequent processing.

Method

Participants. Participants were 94 University of Notre Dame undergraduates recruited from the Psychology Department research subject pool. All participants were naïve to the experimental hypotheses, and received partial course credit for their participation. None participated in any other experiment reported in this manuscript.

Stimuli, design, and procedure

The stimuli were the displays from Experiment 1, with the sentences modified to be of the form 'LETTER *and* LETTER'. The procedure was as in Experiment 1, with participants verifying whether the two letters indicated in the sentences appeared in the display. The design was similar to that used in Experiment 1, except that the prime term factor (*near* vs. *far*) was replaced with prime distance (short and long), with the short distance the same as the distance used on *near* trials in Experiment 1 and the long distance the same as the distance used on *far* trials in Experiment 1; finally, prime/probe term correspondence was replaced with prime/probe distance correspondence.

Results and discussion

Using the criteria described in Experiment 1, data from four participants were discarded because they had $> 30\%$ unacceptable trials. For the remaining 90 participants, 92% of their critical trials were acceptable; the trimmed data for these participants were due to errors on the prime trial (4%), errors on probe trial (3%), errors on both prime and probe trials ($< 1\%$), response time out of range on prime trials ($< 1\%$), response time out of range on probe trials ($< 1\%$), response time out of range on both primes and probes ($< 1\%$) or both errors and response time out of range ($< 1\%$).

Prime and probe response times. Mean prime and probe response times and standard errors as a function of distance correspondence and direction correspondence are provided in Table 1. For prime response times, there was a significant interaction between distance correspondence and direction correspondence, $F(1, 89) = 5.0$, $0^2 = .05$; the main effects of distance correspondence ($F < 1$) and direction correspondence ($F < 2.9$, $p > .08$) were not significant. The interaction was of the form that when the distance matched, prime response times were significantly faster when the direction matched on the subsequent probe trial ($M = 788$ ms) than when the direction mismatched ($M = 811$ ms), $t(89) = 2.98$; however, there was no effect of direction (Ms = 796 ms for direction matched and direction mismatched) when distance mismatched, $t < 1$. As in Experiment 1, these factors are not relevant to the prime trials, as they are defined as a function of the correspondence between prime and probe. Nevertheless, as such differences in processing on prime trials may affect subsequent probe trials, the analyses on the differences take these effects into account.

For probe response times, there was only a significant effect of direction correspondence, with probe trials with matched prime/probe direction significantly faster ($M = 783$ ms) than probe trials with mismatched prime/probe direction ($M = 798$ ms), $F(1, 89) = 4.81$, $0^2 = .05$. The main effect of distance correspondence ($F < 3.0$, $p > .08$) and the interaction between distance correspondence and direction correspondence ($F < 1$) were not significant. The main effect of direction correspondence could indicate the encoding of direction. However, this analysis doesn't take into account any differential processing on prime trials that could be influencing the rate of responding on probe trials. To more directly assess whether direction is encoded, we need to examine the effects of distance correspondence and direction correspondence on the differences between prime and probe trials.

Differences. Mean differences (prime response time – probe response time) are graphed as a function of direction correspondence and distance correspondence in Figure 2, Panel B; error bars are standard errors. There were no significant effects (all Fs < 2.4, ps > .13). As shown in Figure 2B, there was only significant facilitation in the distance-matched/direction-mismatched condition, $t(89) = 2.2$; for the other conditions, ts < 1.4, ps > .19. Unlike Experiment 1, there was no facilitation due to maintaining the direction from prime to probe trials, regardless of whether the distance matched or mismatched. The only facilitation that was observed was when the direction did not match, a finding that is not theoretically predicted. Moreover, this benefit did not differ from the nonsignificant benefit for the distance-matched/direction-matched condition, $t < 1$, and was significantly smaller ($M = 18$ ms) than the term-matched/direction-matched condition of Experiment 1 ($M = 43$ ms), $t(165) = 1.9$, $p = .03$, one-tailed, independent groups. Thus, the data from Experiment 2 suggest that when direction information is not relevant for the task, such information is not encoded. Given that Experiment 1 used the same displays and included similar processing of the identity of the letters, the evidence in favour of the encoding of direction in Experiment 1 is most likely due to the processing of the spatial term, and the subsequent usefulness of direction information to this processing that did not pertain in Experiment 2.

Experiment 3: *Approach* and *avoid*

Most research on spatial language has focused on spatial prepositions. However, other classes of terms such as verbs also convey spatial information (Miller, 1972; Miller & Johnson-Laird, 1976; Morrow & Clark, 1988). Of particular interest in the current paper are path verbs such as *approach* that specify dynamically changing distance information, as in (3) (Jackendoff, 1983; Talmy, 1975, 1985). The specification of distance by these types of verbs may be similar to the specification of distance in (4) that is derived from a spatial preposition. Moreover, the presumed endpoint of the distance in (3) may be similar to the specification of distance in (5).

(3) 'The man approaches the house.'
(4) 'The man nears the house.'
(5) 'The man is near the house.'

Given the apparent similarity in the specification of distance across spatial prepositions and path verbs, the question we asked in Experiment 3 was whether direction information would also be encoded during the interpretation of path verbs that specify information about distance. This would suggest that spatial information is interpreted similarly for prepositions and verbs.

The assumption that distance but not direction is specified by the path verbs *approach* and *avoid* was verified in a norming study in which 37 independent participants were asked to judge the typical distance and direction conveyed by the statements '*A approaches B*' and '*A avoids B*'.[2] With respect to distance, participants were asked to indicate as many of the following five options that applied to the distance conveyed by the verbs: *near, medium, far, could convey ANY distance,* and *conveys NO distance*. The distribution of responses is shown in Table 2. For *approach* ($N = 45$ responses), 80% of the responses were *near* and *medium*, with no *far* responses. For *avoid* ($N = 40$ responses), 75% of the responses were *far*, with no *near* responses. These data indicate that these two verbs seem to convey different distances, with *approach* corresponding to closer distances than *avoid*. This finding is consistent with Kemmerer's (1999) claim that proximal terms are defined in contrast to one another rather than being defined with respect to absolute distances (see also Morrow & Clark, 1988).

With respect to direction, participants were asked to indicate as many of the following 10 options that applied to the direction conveyed by the verbs: A *left of* B, A *right of* B, A *above* B, A *below* B, A *above and left of* B, A *above*

[2] Participants also provided the direction and distance responses for the verbs *attract*, *repel*, *advance*, *retreat*, *ascend*, *descend*.

TABLE 2
Distribution of direction and distance responses for 37 independent participants for *approach* and *avoid*.

	Term	
Distance	*Approach (N = 45)*	*Avoid (N = 40)*
Near	21	0
Medium	12	4
Far	0	30
Any distance	9	3
No distance	3	3
Direction	*Approach (N = 67)*	*Avoid (N = 58)*
Above	4	0
Below	10	0
Left	9	3
Right	9	2
Above/left	4	11
Above/right	8	7
Below/left	2	9
Below/right	5	8
Any direction	15	8
No direction	1	10

Note: N = number of endorsed responses; $N > 37$ because participants were allowed to endorse as many options as applicable.

and right of B, A *below and left of* B, A *below and right of* B, *could convey ANY direction*, and *conveys NO direction*. For *approach* ($N = 67$), the most frequent response ($N = 15$) was ANY direction, with one response corresponding to *NO* direction. When particular directions were selected ($N = 51$), only six corresponded to the selection of a single direction, with variability in which direction was selected (left, right, above, above/left, above/right); the others corresponded to the selection of multiple directions (for example, endorsing *left*, *right*, *above* and *below*). Similarly, for *avoid*, the second most frequent response ($N = 10$) was NO direction, with eight responses indicating ANY direction. When particular directions were selected ($N = 40$), only nine trials corresponded to the selection of a single direction, with variability in which direction was selected (above, below, above/left, above/right); the others corresponded to the selection of multiple directions. These data indicate that *approach* and *avoid* do not convey specific directions.

Given this similarity between *near*/*far* and *approach*/*avoid* in specifying distance but not direction, Experiment 3 used the paradigm from Experiment 1 to investigate whether direction would be similarly encoded during the processing of these motion verbs.

Method

Participants. Participants were 81 University of Notre Dame undergraduates recruited from the Psychology Department research subject pool. All participants were naïve to the experimental hypotheses and received partial course credit for their participation. None participated in any other experiment reported in this manuscript.

Stimuli, design, and procedure

The stimuli were the displays from Experiment 1, with the sentences modified to substitute the terms *approach* and *avoid* for *near* and *far*, respectively. The design was the same as for Experiment 1, except that we included both vertical and horizontal configurations of letters, rather than only the horizontal configurations used in Experiment 1 to ensure that the effects were not specific to horizontal directions. With this change, the 64 critical trial pairs were constructed from 2 (prime term: *approach* vs. *avoid*) $\times$ 2 (prime/probe term correspondence: matched vs. mismatched) $\times$ 4 (prime direction: left to right, right to left, bottom to top, or top to bottom) $\times$ 4 (probe direction: left to right, right to left, bottom to top, or top to bottom). All other aspects of the design and procedure were as in Experiment 1.

Results and discussion

Using the criteria described in Experiment 1, data from 11 participants were excluded. For the remaining 70 participants, 89% of their critical trials were acceptable; the trimmed data for these participants were due to errors on the prime trial (4%), errors on probe trial (4%), errors on both prime and probe trials ($<$ 1%), response time out of range on prime trials (2%), response time out of range on probe trials (2%), response time out of range on both trials ($<$ 1%), and both error and response time out of range (3%).

Prime and probe responses times. Mean prime and probe response times and standard errors as a function of term correspondence and direction correspondence are provided in Table 1. For prime response times, there were no significant effects of direction correspondence, term correspondence, or an interaction, Fs < 1. For probe response times, there was only a significant effect of term correspondence, with probe trials with matched prime/probe terms significantly faster ($M = 918$ ms) than probe trials with mismatched prime/probe terms ($M = 1015$ ms), $F(1, 69) = 66.6$, $0^2 = .49$. The main effect of direction correspondence ($F < 1.2$, $p > .28$) and the interaction between term correspondence and direction correspondence ($F < 2.4$, $p > .12$) were not significant.

Differences. Mean differences (prime response time – probe response time) are graphed as a function of direction correspondence and term correspondence in Figure 2, Panel C; error bars are standard errors. There was a main effect of term correspondence, with the difference between prime and probe trials with matched terms ($M = 70$ ms) significantly greater than the difference between prime and probe trials with mismatched terms ($M = -21$ ms), $F(1, 69) = 62.3$, $0^2 = .48$. The main effect of direction correspondence was not significant ($F = 2.9$, $p > .09$), and there was a trend toward an interaction, $F(1, 69) = 3.2$, $0^2 = .49$, $p = .076$. As shown in Figure 2C, there was significant facilitation when the terms matched across prime and probe pairs, both when the direction matched ($M = 98$ ms) and when the direction mismatched ($M = 41$ ms), ts > 3.7, ps $< .0001$. Note that while the facilitation when the term matched but direction mismatched was likely due to the term repeating from prime to probe trial, there was an additional significant benefit when the direction also matched, as illustrated by a t-test comparing these differences, $t(69) = 2.79$, $p = .007$. These data indicate that the direction was retained from prime to probe trials when the terms matched. In contrast, when the terms mismatched, there was a cost, both when the direction matched ($M = -31$ ms) and when the direction mismatched ($M = -31$ ms), with the latter effect significantly different from 0 ($t(69) = 2.8$, $p = .007$. These effects replicate the results from Experiment 1 demonstrating significant facilitation when the direction matched for prime and probe trials with the same term, and suggest similar processing of direction and distance information for prepositions and verbs.

Experiment 4

Experiment 3 demonstrated that the processing of the motion verbs *approach* and *avoid* were similar to the processing of the spatial prepositions *near* and *far*, with respect to the encoding of direction. One important difference between these types of spatial terms is that the prepositions convey a static relation whereas the motion verbs convey a dynamic relation. In Experiment 3, the displays that were used in conjunction with the motion verbs were static, illustrating only the final endpoint of the motion. In Experiment 4, we used the same displays as in Experiments 1–3, but preceded them with frames that depicted the letters in motion in order to better correspond to the meaning of the motion verbs. Specifically, on *approach* trials, the letters appeared initially at a far distance apart, and a sequence of frames was then presented that showed one letter moving closer to the other letter. The final frame was the display showing the letters at a short distance apart that was used for *near* trials in Experiment 1 and *approach* trials in Experiment 3. For *avoid* trials, the letters appeared initially at a close distance apart, and a sequence of frames was then presented that showed one letter moving away from the other letter. The final frame was the display showing the letters at a far distance apart that was used in the displays for *far* trials in Experiment 1 and *avoid* trials in Experiment 3. If direction information is relevant for finding the target in spatial descriptions using these motion verbs, then there should be facilitation when the direction matches across prime and probe trials, as in Experiments 1 and 3.

Method

Participants. Participants were 56 University of Notre Dame undergraduates recruited from the Psychology Department research subject pool. All participants were naïve to the experimental hypotheses and received partial course credit for their participation. None participated in any other experiment reported in this manuscript.

Stimuli, design, and procedure

The stimuli, design, and procedure from Experiment 3 were used with the exception that the displays were preceded with an animate sequence of frames, each shown for 25 ms, which depicted the first letter moving toward/away from the second letter in equally spaced steps. On *approach* trials, the letters started at a distance of 9.18° of visual angle apart, and ended at a distance of 2.2°; for *avoid* trials, the letters started at a distance of 2.2° apart, and ended at a distance of 9.18°. The final frame corresponded to the static displays used in Experiment 3.

Results and discussion

Using the criteria described in Experiment 1, data from 10 participants were excluded. For the remaining 46 participants, 86% of their critical trials were acceptable; the trimmed data for these participants were due to errors on the prime trial (6%), errors on probe trial (7%), errors on both prime and probe trials (1%), response time out of range on prime trials (2%), and both error and response time out of range (1%).

Prime and probe response times. Mean prime and probe response times and standard errors as a function of term correspondence and direction correspondence are provided in Table 1. For prime response times, there were no significant effects of direction correspondence, term correspondence, or an interaction, $F\text{s} < 1.7$. For probe response times, there was only a significant effect of term correspondence, with probe trials with matched prime/probe terms significantly faster ($M = 864$ ms) than probe trials with mismatched prime/probe terms ($M = 956$ ms), $F(1, 45) = 32.9$, $0^2 = .42$. The main effect of direction correspondence ($F < 1$) and the interaction between term correspondence and direction correspondence ($F < 2.9$, $p > .09$) were not significant.

Differences. Mean differences (prime response time – probe response time) are graphed as a function of direction correspondence and term correspondence in Figure 2, Panel D; error bars are standard errors. There was a main effect of term correspondence, with the difference between prime and probe trials with matched terms ($M = 83$ ms) significantly greater than the difference between prime and probe trials with mismatched terms ($M = -29$ ms), $F(1, 45) = 23.3$, $0^2 = .34$. The main effect of direction correspondence was not significant ($F < 1$), but there was a significant interaction, $F(1, 45) = 4.2$, $0^2 = .096$. As shown in Figure 2D, there was significant facilitation when the terms matched across prime and probe pairs, both when the direction matched ($M = 101$ ms) and when the direction mismatched ($M = 65$ ms), ts > 2.7, ps $< .008$. Note that, as in Experiment 3, there was additional benefit of 36 ms when the direction matched than when the direction mismatched, although this difference failed to reach significance, $t < 1$. When the terms mismatched, there was a significant cost when the direction matched ($M = -72$ ms), $t(45) = 2.7$, $p = .01$, but not when the direction mismatched ($M = 14$ ms). This difference between direction matched and mismatched conditions when the terms mismatched was significant, $t(45) = 2.5$, $p = .02$.

The pattern of facilitation and cost is largely similar across Experiments 3 and 4. One difference is that the additional benefit due to matched direction versus mismatched direction when the terms matched failed to reach significance in Experiment 4, although comparing across Figure 2C and 2D shows an obvious similarity. This may be due to lower power based on fewer participants in this experiment than in Experiment 3. To assess the similarity of the data across Experiments 3 and 4, we combined the differences in a single analysis with term correspondence and direction correspondence as within-subject factors, and experiment as a between-subjects factor. No effects involving experiment were significant; moreover, collapsing across experiment, there was significant benefit when the term matched and direction matched ($M = 100$ ms) and when term matched and direction mismatched ($M = 51$ ms), ts > 4.4, ps $< .0001$, with significant additional benefit occurring when the direction matched than when it mismatched, $t(115) = 2.2$, $p = .03$. This suggests that when the terms matched, direction was also encoded and retained across prime and probe trials. Thus, these data are consistent with Experiment 3 in suggesting that direction and distance information are processed similarly across these two classes (preposition and verbs) of proximal terms.

GENERAL DISCUSSION

The current research assessed whether direction information is encoded during the interpretation of proximal terms. Experiment 1 showed a benefit when letters in a display were configured in the same direction across prime and probe trials during processing of the proximal spatial prepositions *near* and *far*. Experiment 2 demonstrated that this benefit was tied to the processing of these spatial terms; it was not present in a letter identity version of the task using the same displays as in Experiment 1. Experiment 3 showed similar facilitation for the proximal verbs *approach* and *avoid* using the same displays as in Experiment 1, and Experiment 4 showed the same pattern using dynamic versions of the displays. In all, the results suggest that direction information was encoded during the processing of these proximal terms. This is an interesting finding, because direction information is not explicitly provided by these spatial terms. More generally, in conjunction with Carlson and Van Deman (2004), the results suggest that the information that is encoded in conjunction with a spatial term is not limited to the information conveyed by the term's meaning, but may include other information that is also available. The fact that such information was not encoded in the identity task of Experiment 2 suggests that the encoding of this additional information is not obligatory; rather, it is only encoded when it is deemed relevant for the task. These studies together suggest that both distance and direction seem important for specifying a target's location.

Encoding distance and direction

Given such evidence that distance and direction are encoded during the processing of spatial terms, one might ask where such information is provided, and how it is encoded. With respect to the source of the AQ1 information, for distance, as reflected in the data by Logan (1996) for *near* and *far* and by the norming data in Table 2 for *approach* and *avoid*, these proximal terms convey a consistent sense of distance but not direction. However, the distance that is conveyed by these terms is variable, depending in large part on the nature of the objects being related (see Morrow and Clark (1988) for *approach* and Carlson and Covey (2005) for *near* and *far*), and on the situational context (Kemmerer, 1999). This is consistent with the idea that the interpretation of spatial terms is constrained by a variety of factors beyond the geometric configuration of the objects, including functional interaction, object knowledge, and dynamic-kinematic routines (see Coventry & Garrod, 2004). Similarly, with respect to direction, because this information is not indicated by the spatial term, it must be obtained from the display, and would presumably be influenced by these same factors. For example, Carlson and Covey (2005) found an influence of object properties on the distance that was inferred between two objects that were spatially related by projective terms that did not explicitly convey distance (e.g., *left*, *front*). For the current study and in Carlson and Van Deman (2004), direction and distance information are directly provided by the configuration of the letters in the displays.

With respect to how distance and direction are encoded, Carlson and Van Deman (2004) suggest that attention is a possible mechanism. Logan (1995) argues that attention is a necessary component of processing spatial terms, and discusses the interpretation of spatial descriptions as involving a shift of attention from one object to the other object. As such a shift would involve both a specific direction and distance, attention could be the mechanism by which a specific value was associated with these parameters. Note that such a shift would also be expected in the identity 'and' task of Experiment 2, in which participants had to verify whether each of the objects in the sentence were present in the display. Thus, the attentional shift would occur for both tasks, with specific values for direction and distance available. However, it is only in the task involving the interpretation of a spatial term that such information is valuable, and therefore encoded and maintained across trials. In contrast, in the identity task, such information is not relevant, and so although available, these values are not encoded.

Proximal terms: Prepositions and motion verbs

The similarity between the processing of spatial information within path motion verbs such as *approach* and *avoid* and spatial prepositions such as *near* and *far* may not be surprising, given that in English, path verbs are largely insensitive to properties of the objects being related (Bowerman, 1996), much like the spatial prepositions (Landau & Jackendoff, 1993; Talmy, 1983). This suggests that similar representations and processes could operate on the interpretation of the spatial information conveyed by these two classes of terms. For example, the distance and direction information could be represented as parameters within a spatial reference frame (Logan, AQ1 1996). Such similarity in processing and representation has important implications for work on motion verbs. Past research on motion verbs has largely focused on distinctions between types of verbs, such as path-of-motion (e.g., exit, approach) vs. manner-of-motion (e.g., run) (Choi & Bowerman, 1991; Naigles, Eisenberg, Kako, Highter & McGraw, 1998; Talmy, 1975). Within path verbs, there has been theoretical (e.g., Jackendoff, 1983) and empirical (Lakusta & Landau, 2005) work focusing on the source and goal. The data in the current study suggest that the spatial component of these verbs is also worthy of examination. This idea could be integrated into work on source and goal by examining the way in which the values associated with the parameters of a reference frame change as a function of the dynamic representation of the motion verbs. For example, the processing of a verb such as *approach* could involve a change in the distance parameter from a long value at the source of the path to a short value at the goal of the path. Note that in the dynamic scenes of Experiment 4, the interpretation of the spatial term was tied to the final display that depicted the goal of the path; thus, the setting assigned to the distance parameter would be the setting associated with the goal of the path. In this light, it is interesting to note that the facilitation due to this setting (for matched terms, direction matched – direction mismatched: $M = 36$ ms) did not differ significantly from the facilitation observed for the static displays depicting the endpoint associated with the motion verbs in Experiment 3 (for matched terms, direction matched – direction mismatched: $M = 56$ ms), nor from the facilitation observed with displays depicting the static relation for the prepositions in Experiment 1 (for matched terms, direction matched – direction mismatched: $M = 67$ ms), $F < 1$.

Nevertheless, there may be differences in processing motion verbs and prepositions due to the dynamic versus static nature of these terms that may have consequences for the encoding of spatial information such as direction. For example, considerable work on representational momentum has suggested that for moving stimuli, the representation of final location is displaced in the direction of the motion (for review, see Hubbard, 2005). In addition, Matlock (2004) has suggested that the processing of fictive motion verbs involves mental simulation of the motion. More generally, the similarity and differences observed in processing direction information across verbs and prepositions may lead to a better understanding not only of the way in which spatial reference frames are used during the interpretation of spatial terms more generally, but also of the relationship between dynamic and static representations.

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