Journal of Memory and Language 84 (2015) 167–189

Contents lists available at ScienceDirect

Journal of Memory and Language

journal homepage: www.elsevier.com/locate/jml

Words, objects, and locations: Perceptual matching explains spatial interference and facilitation

Zachary Estes [a,*], Michelle Verges [b], James S. Adelman [c]

[a] Bocconi University, Milan, Italy
[b] Blissfully Unaffiliated, USA
[c] University of Warwick, Coventry, England, United Kingdom

ARTICLE INFO

Article history:
Received 3 December 2014
revision received 8 June 2015

Keywords:
Concreteness
Imageability
Linguistically mediated visual search
Perceptual simulation
Visual strength
Visuo-spatial attention

ABSTRACT

Many common words have spatial associations (e.g., "bird," "jump") that, counterintuitively, hinder identification of visual targets at their associated location. For example, "bird" hinders identification at the top of a display. This spatial interference has been attributed to perceptual competition: "bird" shifts attention upward and evokes the perceptual representation of a bird, which impairs identification of an unrelated target by preoccupying the visual system. We propose an alternative explanation based on perceptual matching: target objects and locations are coded independently for their congruence with the cue word, and codes that are inconsistent with one another hinder identification. Two experiments demonstrated that whereas semantically mismatching targets elicit spatial interference, semantically matching targets elicit spatial facilitation. Two further experiments demonstrated that cue words of strong (e.g., "bird") and weak (e.g., "arise") visual strength and imageability elicited equivalent spatial interference. Results suggest that spatial interference is attributable to perceptual matching rather than perceptual competition. Moreover, results supported a graded model of perceptual matching, whereby target identification times are proportional to the physical distance between the expected (i.e., associated) and observed (i.e., actual) target locations.

Introduction

Many common words have spatial associations. For instance, the words "bird" and "jump" have upward associations, whereas "snake" and "crawl" have downward associations (Meteyard & Vigliocco, 2009; Zwaan & Yaxley, 2003). Moreover, words that have spatial associations guide visual attention toward the associated location and thus influence perception. "Bird" and "jump" direct attention upward, whereas "snake" and "crawl" direct attention downward (e.g., Dudschig, Souman, Lachmair, de la Vega, & Kaup, 2013; Estes, Verges, & Barsalou, 2008; Gozli, Chasteen, & Pratt, 2013; Quadflieg et al., 2011). However, the effect of such linguistic orienting on visual perception may be counter-intuitive: Language often *interferes* with visual perception at an associated location. For instance, "bird" elicits slower identification of a visual target presented at the top of a display than to that same visual target presented at the bottom of the display. We refer to this as the *spatial interference effect*. Although this effect has been demonstrated many times, its theoretical explanation remains relatively unexplored. The present study thus aims to test two contrasting explanations of the spatial interference effect. First we briefly review the evidence for this effect.

* Corresponding author.
E-mail addresses: estes@unibocconi.it (Z. Estes), MichelleVerges@gmail.com (M. Verges), J.S.Adelman@warwick.ac.uk (J.S. Adelman).

http://dx.doi.org/10.1016/j.jml.2015.06.002
0749-596X/

The spatial interference effect

Language may interfere with visual perception at an implied location. In the initial demonstration of this effect, Richardson, Spivey, Barsalou, and McRae (2003) presented sentences with verbs that had either a vertical association (e.g., "The eagle flies to the river") or a horizontal association (e.g., "The miner pushes the cart"), and then they presented a visual target (i.e., ● or ■) at the top, bottom, left, or right of a display. Participants simply identified the target as a square or a circle. Vertically associated sentences interfered with target detection on the vertical axis. For instance, after hearing "The eagle flies to the river", targets were detected significantly more slowly at the top and bottom locations than at the left and right locations. Richardson et al. thus revealed a spatial interference effect, however they did not report separate analyses of upward and downward stimuli. Bergen, Lindsay, Matlock, and Narayanan (2007) presented sentences with upward (e.g., "The mule climbed") or downward (e.g., "The chair toppled") motion verbs, followed by a square or circle at the top or bottom of a display. Upward and downward verbs respectively elicited slower target identification at the top and bottom of the display, thereby demonstrating an interference effect that was specific to the location associated with the verb. This location-specific spatial interference was replicated in a second study using upward (e.g., "The ceiling cracked") and downward association nouns (e.g., "The cellar flooded"). Estes et al. (2008) obtained the same effect with single word cues. They presented words denoting objects that typically occur upward (e.g., "hat") or downward (e.g., "boot") in the visual field, followed by a visual target (i.e., X or O) at the top or bottom of a display. Target identification was significantly slower in the denoted object's typical location. For example, "hat" and "boot" elicited slower responses at top and bottom locations, respectively. Verges and Duffy (2009) further replicated this spatial interference effect with both nouns and verbs. Thus, spatial interference[1] has been demonstrated many times by several research groups (see also Gozli et al., 2013).

Strikingly, the spatial interference effect occurs despite the utter irrelevance of the spatial cue for judgment of the target object. To begin with, participants could successfully complete the task of identifying the target object (e.g., ● or ■) without even reading the spatial cues. And indeed, in this paradigm, the cue word (e.g., "bird") never matches the target object (e.g., ●) on a single trial of the experiment. So why does the cue word have any effect at all on target identification? Presumably, the cue words are effective because in many circumstances such linguistic orienting facilitates perception and action (e.g., Barsalou, 2009; Hommel, 2004; Miller & Johnson-Laird, 1976): Words guide visual attention toward objects that might be the referent, thereby facilitating perception of the denoted object among an array of distracters (Altmann & Kamide, 2007; Dahan & Tanenhaus, 2005; Spivey, Tyler, Eberhard, & Tanenhaus, 2001). For instance, "snake" guides attention to curved objects (Dahan & Tanenhaus, 2005). The spatial interference effect presumably also arises from this linguistically mediated visual search. But whereas those prior studies revealed an object-based search (Altmann & Kamide, 2007; Dahan & Tanenhaus, 2005; Spivey et al., 2001), in which the cue word (e.g., "snake") induces a search for the referent's associated features (i.e., curved), the spatial interference effect instead reveals a location-based search, in which the cue induces a search in the referent's associated location (i.e., downward). If snakes are seen most often in the lower visual field, and if "snake" shifts one's attention downward, then "snake" would guide one's visual search toward the referent's most likely location. The cue word thus induces a search for its referent, even though the target object never matches the cue word in this paradigm, and even though the task could be completed successfully without reading the cue word. The spatial interference effect thus appears to be quite compelling.

Location-specific perceptual representation

Words denoting objects (e.g., "sun") and events (e.g., "rise") activate spatial representations that direct attention to their associated location (e.g., up). But why should they interfere with rather than facilitate perception at that associated location? Why does "sun" temporarily blind the perceptual system at the top of a display? In addition to activating spatial associations, words have long been known to activate perceptual representations (e.g., Miller & Johnson-Laird, 1976), which in more recent terminology is often called "perceptual simulation" (for review see Barsalou, 2008; Gallese & Lakoff, 2005). For example, the word "lemon" activates the appearance, taste, smell, and feel of previously experienced lemons. Many studies have shown that hearing a word activates the cortical networks involved in the actual perception or execution of the denoted object or action (Martin, 2007; Pulvermuller & Fadiga, 2010), and many others have demonstrated that words affect perception and action (Fischer & Zwaan, 2008; Pecher & Zwaan, 2005; Zwaan & Taylor, 2006). Such perceptual representations can be intentionally generated and consciously perceived, as with mental imagery, but perceptual representations activated during ordinary language processing appear to occur without conscious awareness (Pecher, van Dantzig, & Schifferstein, 2009).

Thus the standard explanation of the spatial interference effect is that words evoke location-specific perceptual representations, which entail both (1) attentional orienting

[1] This spatial interference effect differs both methodologically and theoretically from the *spatial iconicity effect*, whereby words elicit faster responses when presented or responded to in their associated (iconic) location. That is, upward association words (e.g., "eagle") elicit faster responses when presented at the top of a display or when responding entails upward movement or pressing a high button, whereas downward association words (e.g., "snake") elicit faster responses when presented at the bottom of a display or when responding entails downward movement or pressing a low button (Kaup, De Filippis, Lachmair, de la Vega, & Dudschig, 2012; Lachmair, Dudschig, De Filippis, de la Vega, & Kaup, 2011; Lebois, Wilson-Mendenhall, & Barsalou, in press; Meier, Hauser, Robinson, Friesen, & Schjeldahl, 2007; Schubert, 2005; Thornton, Loetscher, Yates, & Nicholls, 2013; Zwaan & Yaxley, 2003; Šetić & Domijan, 2007). Methodologically, the iconicity effect differs from the interference effect in that iconicity entails responding to the word itself rather than a separate visual target. Theoretically, spatial interference thus can be used to test predictions about spatial cueing and visual perception, whereas spatial iconicity cannot. The present research investigates only the spatial interference effect.

and (2) activation of perceptual representations. To illustrate, the word "bird" evokes (1) a high spatial association that shifts attention upward, and (2) a visual representation of a bird in that location. Critically, because this visual representation of a bird is incompatible with the visual target (e.g., ■), the representation effectively masks target identification at the associated location (Estes et al., 2008; Verges & Duffy, 2009). A similar explanation supposes that the perceptual representation engages the neural systems necessary for judging the visual target, thus creating interference in the form of neural competition (Bergen et al., 2007; Richardson et al., 2003). Although they assume different levels of explanation – i.e., perceptual masking or neural competition – both of these descriptions attribute the spatial interference effect to the activation of visuospatial representations that compete with the visual target for perceptual processing. We thus refer to this as the *competition account* of spatial interference.

The first assumption – attentional orienting – is empirically supported. When people attempt to remember a recently viewed object that is no longer present, they nevertheless tend to redirect their eyes toward and fixate on the location at which they previously viewed the object (Richardson & Spivey, 2000; Spivey & Geng, 2001). More generally, object words facilitate eye movements toward the denoted object's typical location (Dudschig et al., 2013). For instance, "bird" and "snake" respectively facilitate upward and downward eye movements. In fact, the distinct patterns of neural activation involved in judgments of "bird" and "snake" closely resemble actual perceptions in the upper and lower visual fields, respectively (Quadflieg et al., 2011; see also Zhang et al., 2013). Although such attentional orienting is well documented, notice that it should facilitate perception at the implied location, not hinder it (Hommel, Pratt, Colzato, & Godijn, 2001).

The counterintuitive direction of the effect (i.e., interference) is instead thought to arise from the activation of perceptual representations, which are hypothesized to visually mask or neurally compete with the visual target. The general claim that language evokes perceptual representations is supported by an overwhelming body of evidence (for reviews see Barsalou, 2008; Fischer & Zwaan, 2008; Gallese & Lakoff, 2005; Martin, 2007; Pecher & Zwaan, 2005; Pulvermuller & Fadiga, 2010). However, the specific claim that perceptual representations cause the spatial interference effect has received little empirical investigation.

Perceptual matching

We propose an alternative explanation of the spatial interference effect, based on a process of perceptual matching. This *matching account* makes two critical assumptions. First, supported by the prior evidence of linguistically mediated visual search (Altmann & Kamide, 2007; Spivey et al., 2001), the matching account assumes that when a cue word is followed by a to-be-identified visual target, people attempt to determine whether the visual target is related to the cue word. Although the cue word is irrelevant to target identification in this paradigm, people tend to search the visual world for the referent of a verbal cue even when it is absent (Dahan & Tanenhaus, 2005; Richardson & Spivey, 2000; Spivey & Geng, 2001). In fact, we assume that this search for a cue's referent is overgeneralized, occurring even in tasks where the cue's referent is never present.[2] The second critical assumption is that, in their attempt to determine whether the target is related to the cue, people judge the target's congruence with both (1) the cued object and (2) its associated location. For instance, a "bird" cue induces one to check whether the perceptual target (1) appears at a bird-associated location and (2) is related to the concept of a bird. Thus the target object and its location are both, independently, coded for their congruence with the cue word. Each object or location code indicates whether the visual target *matches* or *mismatches* the cue, which for simplicity we specify here with + and − respectively. For example, "bird" followed by an unrelated target (e.g., "X") at the top of the display is coded as O− L+, because a mismatching object (O−) appears at a matching location (L+). We further refer to two object and location codes as *consistent* when they both match or both mismatch the cue word (i.e., O+ L+ and O− L−) and as *inconsistent* when one code matches but the other code mismatches the cue (i.e., O+ L− and O− L+).

Our critical claim is that inconsistent codes predict slower target identification, because they represent a perceptual ambiguity about the target's identity. Specifically, inconsistent object and location codes indicate conflicting evidence about whether the target object is the cue's referent. In the spatial interference paradigm, the target object always mismatches the cue word (O−). Consequently, when the target appears in the matching location (O− L+), this provides ambiguous evidence of whether the cue's referent is present or not. The participant thus seeks to disambiguate whether the target is related to the cue word, and only after the cue's referent is determined to be absent does the participant then proceed to identify the target object. Thus, the perceptual ambiguity introduced by inconsistent codes (O− L+) causes a brief delay before the actual target is identified. In contrast, when that same target appears in the mismatching location (O− L−), both codes indicate that the target is not the cue's referent, and hence the participant immediately proceeds to determine what the target object is after all.[3]

[2] Indeed, such an overgeneralization may be adaptive. Suppose someone says "snake" to you. If there is a snake nearby, then you will perceive it faster and respond to it sooner if the word had evoked a visual search than if it had not. If there is not a snake nearby, then you will lose a bit of time searching for a snake that is not there. The behavioral benefit of quickly perceiving a present target presumably outweighs the behavioral cost of time spent searching for an absent target.

[3] This hypothesized coding of objects and locations as matches (+) or mismatches (−) is reminiscent of the polarity correspondence principle, which states that stimulus and response dimensions are coded as +polarity or −polarity, and that responding is faster when those stimulus and response polarities correspond (see Proctor & Cho, 2006). For instance, positive words are +polar, and up is also +polar, so positive words elicit faster responses when presented at the top of a display (Lakens, 2012; Lynott & Coventry, 2014). Upon closer scrutiny, however, polarity correspondence cannot explain the spatial interference effect. Upward cues and top targets are both +polarity, so polarity correspondence predicts fast responding. In contrast, upward cues (+polarity) do not correspond with bottom targets (−polarity), so polarity correspondence predicts slow responding. Notice that these predictions are of spatial facilitation. Polarity correspondence thus cannot explain the spatial interference effect (see also Santiago & Lakens, 2015).

To illustrate, suppose the cue word "bird" precedes a square target at the top of a display (cf. Bergen et al., 2007; Estes et al., 2008; Richardson et al., 2003; Verges & Duffy, 2009). Because the target is in the associated location, it is coded as a location match (L+). But because it is an unrelated object, it is coded as an object mismatch (O−). These inconsistent codes (O− L+) evoke further perceptual processing to determine whether the visual target is a bird-related object, and this delays responding. Now suppose "bird" precedes a square target at the bottom of the display. Although the object and location of the visual target both mismatch the cue word, crucially, those consistent O− and L− codes both indicate that the target is unrelated to the cue. And because no further processing is required to determine whether the target is bird-related, the task response proceeds without further delay. So counter-intuitively, given a visual target that is unrelated to the cue word (as in all prior demonstrations of the spatial interference effect), responding would be faster to targets that are *not* in the associated location than to targets that *are* in the associated location.

This matching account explains spatial interference not only from nouns such as "bird", but also from verbs such as "jump" (Bergen et al., 2007; Richardson et al., 2003; Verges & Duffy, 2009). Given that many events (and the verbs that denote them) have visuo-spatial representations (e.g., Meteyard & Vigliocco, 2009; for review see Hommel, 2004; Zacks, Speer, Swallow, Braver, & Reynolds, 2007), the matching account explains interference from verbs in the same way that it explains interference from nouns: A square target at the top of the display does not visually represent jumping any more than it represents a bird. Thus regardless of whether the cue is "bird" or "jump", a top visual target is an unrelated object in the associated location, thereby evoking inconsistent codes (O− L+) that induce further processing and hence delay responding.

Both general tenets of this account – that objects and locations are coded independently, and that inconsistent codes hinder responding – have received much empirical support in other related domains. Indeed, a wealth of evidence indicates that objects and locations are processed respectively in the ventral and dorsal pathways of the visual object recognition system in the human brain (for review see Ungerleider & Haxby, 1994), and many other studies have demonstrated that conflicting spatial codes between stimulus and response tend to hinder responding (for review see Lu & Proctor, 1995). This does not imply, of course, any support for the more specific claim that inconsistent object and location codes cause the spatial interference effect. The following experiments tested this account.

The present study

In sum, the competition account attributes spatial interference to visual representations (i.e., the cue visually or neurally masks the target), whereas the matching account attributes spatial interference to spatial associations (i.e., the object and location codes are inconsistent). There is much evidence that words evoke both spatial associations and visual representations, but no prior study has tested which of these explains the spatial interference effect. We therefore conducted four experiments that tested these accounts. Experiments 1 and 2 tested a fundamental assumption of both models: Although visual targets that are semantically unrelated to the cue word elicit spatial interference (as described above), semantically matching visual targets should elicit facilitation instead. That is, "bird" should facilitate perception of a bird at the top of a display. Surprisingly, this basic assumption of both accounts has not previously been tested. After obtaining evidence of both spatial interference and facilitation in Experiments 1 and 2, then Experiments 3 and 4 critically discriminated between these accounts, which make differential predictions concerning effects of abstract cue words such as "love" and "lapse". Simply stated, if spatial interference were caused by visual representations (i.e., the competition account), then abstract cue words should elicit less interference than concrete cue words. In contrast, if spatial interference were due to spatial associations (i.e., the matching account), then *any* cue word with spatial associations could elicit strong interference. These predictions are developed more fully after Experiments 1 and 2.

Experiment 1

All prior demonstrations of the spatial interference effect used semantically unrelated visual targets such as "X" and "O" or ■ and ●. Somewhat surprisingly, the more naturalistic case in which a cue word is followed by its denoted object has yet to be tested. Thus, in the present experiment we presented spatially associated cue words (e.g., "bird") followed by a visual target that was either semantically matching (i.e., an image of a bird) or semantically mismatching to the cue (e.g., an image of a wrench) and that appeared in either the associated location (i.e., top) or the opposite location (i.e., bottom). We also included some trials in which the visual target was not a real object (i.e., arbitrary shapes and lines), and participants' task was to indicate whether the target was a real object.

This experiment provides a critical test of the competition and matching accounts, but it does not discriminate between them. As described above, both accounts explain the interference effect with semantically mismatching targets (e.g., "bird" followed by an image of a wrench). In contrast, both accounts predict a facilitation effect with semantically matching targets (e.g., "bird" followed by an image of a bird). By the competition account, the cue word elicits a perceptual representation of the cue in its associated location. When the pre-activated visual target then appears in that location, perception is facilitated. By the matching account, when the object and location codes both indicate a cue-target match (O+ L+), the target is identified as the cue's referent. But when that matching target appears in an unassociated location (O+ L−), those inconsistent codes briefly delay recognition of the cue's referent as the target object. Thus, both accounts predict an interaction, with interference from semantically mismatching targets in the associated location but facilitation from matching targets in the associated location.

Methods

Participants

Forty-one undergraduates at the University of Warwick participated for £3.

Stimuli

Cues were twenty concrete nouns with spatial associations (10 upward, 10 downward) sampled from prior studies on language and spatial attention (Bergen et al., 2007; Estes et al., 2008; Richardson et al., 2003; Verges & Duffy, 2009). Upward cues were "bird", "cloud", "flag", "forest", "galaxy", "hat", "palace", "plane", "satellite", and "star"; downward cues were "arrow", "bottle", "bowl", "coin", "fork", "insect", "lobster", "shoes", "slippers", and "snake". Targets were black-and-white line drawings. Twenty "semantically matching" targets depicted the cue words, and 20 "semantically mismatching" targets depicted real objects that were unrelated to the cue words (e.g., ticket). Note that if the mismatching targets also had upward or downward associations, those target associations could interact with the spatial associations of the cues. So given that our primary interest was spatial effects of the cues, we used semantically mismatching targets that had neutral spatial associations. All but four of these 40 cues and targets were included in a norming study by Verges and Duffy (2009), who had participants rate the extent to which each word referred to an object typically associated with upward or downward locations (1 = downward, 7 = upward). The downward (*Range* = 2.50–3.14) and upward cues (*Range* = 4.45–6.64) had non-overlapping ranges of spatial associations. The semantically mismatching targets were clustered around the neutral midpoint of the scale and did not overlap with the upward and downward cues (*Range* = 3.18–4.14). An additional twenty targets consisted of novel shapes and lines that did not depict a recognizable object; these targets served as the non-objects.

Procedure

The experiment was conducted in individual sessions within a sound-attenuated room, with participants seated at a standard desktop computer. Full instructions are provided in the online Supplementary Materials, and the trial procedure is illustrated in Fig. 1. Participants initiated each trial by pressing the space bar, which evoked a blank inter-stimulus interval (250 ms), followed by a central fixation (250 ms), a central cue word (100 ms), and another blank inter-stimulus interval (50 ms). Finally, a target appeared at either the top or bottom of the display and remained onscreen until the participant indicated via key press whether it was a real object (M key) or not (X key). Following prior studies (e.g., Estes et al., 2008), we used a short 150 ms delay between cue and target onsets in order to exclude potential explanations based on inhibition of return, which is thought to emerge approximately 200–300 ms after cue onset (see Klein, 2000). Incorrect responses elicited an error message ("WRONG!") before proceeding to the next trial. The inter-trial interval (ITI) was 1 s. Each cue (e.g., "bird") appeared with three targets: semantically matching (i.e., image of a bird), semantically mismatching (i.e., image of a wrench), and non-object (i.e., a nonsense image). Moreover, each cue appeared with each of those three objects twice: once at the top and once at the bottom of the display. In total then, each cue appeared six times, such that semantically matching and mismatching objects and non-objects were equiprobable at top and bottom locations. Thus there were 120 trials per participant (i.e., 20 cues $\times$ 3 targets $\times$ 2 locations), randomized individually within-participants. Participants completed twelve practice trials prior to the experimental trials.

Results

Analyses and reporting

For each experiment reported in this paper, data were analyzed via mixed effects regression modeling with participants and items as crossed random effects.[4] Results are reported in terms of the unstandardized regression coefficient, *B*. For each experiment, all significant effects ($p < .05$) are described in the text, and any effect not described in the text was not significant. However, full results (including nonsignificant effects) are available online as Supplementary Materials.

Outliers

Outlying response times more than 2.5 *SD*s from the mean, calculated separately for each participant and each condition, were removed from analyses (2.50% of trials). Response times from trials that elicited an error were also excluded from analyses (3.68% of trials). Additionally, one outlying participant whose overall mean error rate was more than 2.5 *SD*s beyond the group mean was excluded from all analyses (2.44% of participants). The analyses reported below thus were calculated across 40 participants.

Error rates

Errors were rare and random. A logistic mixed effects regression[5] found no significant effects or interactions of spatial association (upward, downward), target object

[4] Our strategy with respect to the random terms was to aim to use maximal structure: that is, include random slopes with respect to subjects for within-subject manipulations and random slopes with respect to cue words for within-item manipulations (Barr, Levy, Scheepers, & Tily, 2013). All categorical variables were binary and were coded using centered variables so that the presence of interactions did not break the interpretation of main effects. We used models that did not estimate the correlations of the random effects, as these terms have negligible influence on results (Barr et al., 2013, Appendix) and hinder convergence. In several cases, particularly those involving error rates, it was not possible to use the desired structure due to failure to converge. We sought to drop random slopes to achieve convergence in those cases, and report these results; in no case was there a difference in conclusion between treating the unconverged estimates as accurate or using the model with random slopes dropped. In some more serious cases involving error rates, the only solution was to fit two models, one with subjects random and one with items random; these yielded consistent results with one another, and in any case, our conclusions are based on the patterns in RTs not those in errors. Where one of these fallback strategies was used, the relevant results are footnoted accordingly.

[5] By-subject and by-items regressions had to be run separately. No random slopes could be fitted in either model without removing the random intercept. In all cases, no effect approached significance because accuracy was practically at ceiling.

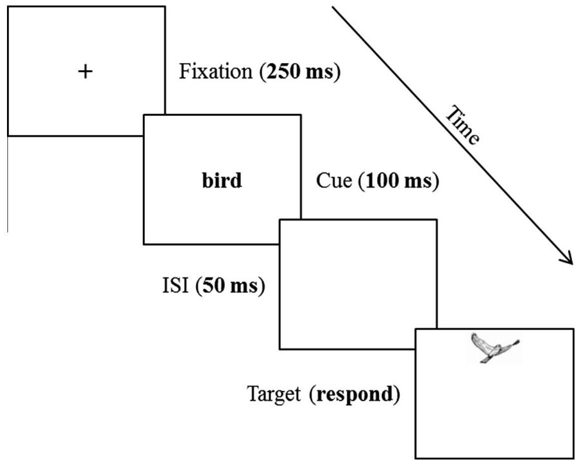

Fig. 1. Trial procedure of Experiments 1 and 2, illustrating a trial with an upward cue followed by a matching object at the top target location. In terms of object (O) and location (L) coding, this represents an O+ L+ trial.

(semantically matching, mismatching), or target location (top, bottom), all $p > .10$.

Response times

Response times were analyzed via linear mixed effects regression with participants and items as crossed random effects, with spatial association, target object, target location, and all possible interactions as categorical predictors. The effect of target object was significant, $B = -46.96$, $t = 3.22$, $p = .001$, with faster responses to semantically matching targets than to mismatching targets. That is, responding was faster when the cue's referent was present than it was absent. More importantly, the predicted 3-way interaction was also significant, $B = -53.43$, $t = 2.56$, $p = .01$. As illustrated in Fig. 2, the semantically mismatching targets exhibited a spatial interference effect. Follow-up analyses examining only the semantically mismatching targets confirmed that this spatial interference effect was indeed significant, evident here as a spatial association × target location interaction, $B = 34.52$, $t = 1.98$, $p = .05$. Analyses examining only the semantically matching targets revealed only a significant effect of target location, $B = -17.97$, $t = 2.51$, $p = .01$, with faster responses at the top location than at the bottom. These semantically matching targets exhibited a nonsignificant trend ($p = .19$) toward spatial facilitation (see Fig. 2). Specifically, the matching object targets following an upward cue (i.e., the two light bars at the right of Fig. 2) exhibited spatial facilitation, but the downward cues elicited no effect.

Discussion

The predicted 3-way interaction was obtained, but whereas the spatial interference effect with semantically mismatching targets was significant, the spatial facilitation effect with semantically matching targets did not reach significance. As in prior studies (Bergen et al., 2007; Estes et al., 2008; Gozli et al., 2013; Verges & Duffy, 2009), cue words elicited slower responses (17 ms slower) to semantically mismatching targets appearing at the associated location than at an unassociated location. For example, "bird" elicited slower recognition of a wrench at the top of the display than at the bottom. In contrast, cue words elicited faster responses (10 ms faster) to semantically matching targets appearing at the associated location than at an unassociated location. For instance, "bird" elicited faster recognition of a bird at the top of the display than at the bottom. However, the lack of a significant facilitation effect with matching targets obscured our theoretical conclusions.

Experiment 2

In attempt to clarify our theoretical conclusions, Experiment 2 provided a more powerful test of the predicted spatial facilitation effect with semantically matching targets. We increased statistical power by substantially increasing both the number of participants (from 41 in Experiment 1 to 100 in Experiment 2) and the number of items (from 20 in Experiment 1 to 60 in Experiment 2). In order to keep the experiment short enough to maintain participants' attention, we used only semantically matching targets in Experiment 2. Thus the design was a 2 (spatial association: upward, downward) × 2 (target location: top, bottom) within-participants experiment, and the method was the object decision task used in Experiment 1. The competition account and the matching account both predict spatial facilitation (for explanation see Experiment 1), which would be evident here as an interaction. The experiment was conducted online, with participants recruited from Amazon's Mechanical Turk, and with stimuli presented and response times recorded with millisecond accuracy via JavaScript. The use of Mechanical Turk for participant recruitment in behavioral research has been extensively validated (for review see Paolacci & Chandler, 2014), as have the accuracy and reliability of response times collected online via JavaScript (Reimers & Stewart, 2015).

Methods

Participants

Given the nonsignificant facilitation effect observed in Experiment 1 ($N = 41$), combined with the decreased environmental control of an online study, here in Experiment 2 we decided to recruit 100 participants. Thus, 100 US-based respondents on Mechanical Turk were paid $2.00 for participation. An additional 100 respondents were paid $0.50 for participating in a spatial rating pre-test.

Spatial rating pre-test

From prior studies of language and spatial attention (Bergen et al., 2007; Estes et al., 2008; Richardson et al., 2003; Verges & Duffy, 2009) we selected nouns denoting common objects. We then supplemented this initial list with additional object nouns that, by our intuitions, fully spanned the range of spatial associations. The final list consisted of 180 concrete nouns, which were presented in

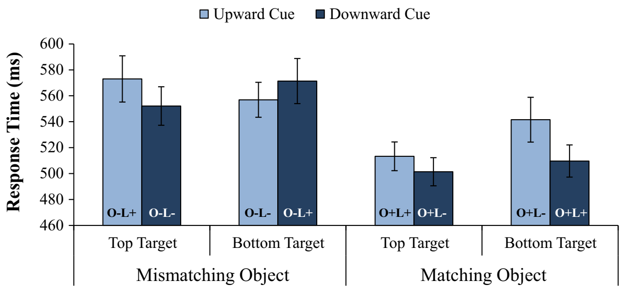

Fig. 2. Response times ($M \pm SE$) to semantically mismatching or matching target objects presented at the top or bottom of a display following cue words with upward or downward associations, Experiment 1. Object (O) and location (L) codes are provided at the base of each bar.

individually randomized order to 100 participants. For each item participants indicated where on the vertical axis they would expect to see the object, on a scale from 1 (“extremely low”) to 5 (“extremely high”). However, participants could alternatively indicate that they would expect to see the object “nowhere in particular”; this option was intended to exclude spatially indeterminate words from the experiment. Full instructions are provided in the online Supplementary Materials, and full results are reported in Appendix A.

Stimuli

Sixty cue words were selected from the Spatial Rating Pre-Test. First, any word that received 20% or more of the spatially indeterminate “nowhere” responses was excluded. We then selected the 30 words with the lowest mean ratings and the 30 words with the highest mean ratings, with the constraint that we were also able to obtain a suitable line drawing of the denoted object (to be used as visual targets). The downward (*Range* = 1.13–1.67) and upward cues (*Range* = 3.64–4.94) had non-overlapping ranges of spatial associations. Object targets were 60 black-and-white line drawings of the objects denoted by the cue words. Non-object targets were the same 20 nonsense images of pseudorandom shapes and lines used in Experiment 1.

Procedure

The procedure was similar to Experiment 1, except that it was modified for web-based data collection. Instructions are provided online as Supplementary Materials. We strongly discouraged inattentive participants by clearly informing them of the demanding nature of the task. Moreover, only users with a successful task completion rate of greater than 99% and with at least 100 tasks completed were eligible to participate. Upon accepting the task in Mechanical Turk, respondents were re-directed to an external website that hosted the experiment, which was presented as an HTML webpage with JavaScript code running locally in each participant’s browser. The procedure required use of a keyboard and a minimum screen resolution, thereby excluding users on most mobile devices (e.g., tablets and phones).

The trial procedure was identical to Experiment 1, except that the ITI was reduced to 500 ms in order to reduce the duration of the experiment. Each of the 60 cues appeared four times: object target at the top, object target at the bottom, non-object target at the top, and non-object target at the bottom. Thus there were 240 trials in total, randomized individually within-participants. At the conclusion of the experiment, participants received a password consisting of a string of digits generated randomly for each participant. They then returned to the Mechanical Turk website, where they copied this password into a textbox in order to validate their participation and receive payment. They also were asked if there was anything that they wanted to tell us about the task, and a textbox was provided for their responses.

Although we pre-determined our sample size to be 100 participants, we ran the experiment across two days, with 50 participants per day. Because our use of web-based methods for response time measurement was relatively novel to the field and absolutely novel to us, we chose to trial it on 50 participants, from whom we could (a) examine the reliability of their datasets and (b) receive their feedback. Our initial check indicated that the data appeared to be reliable, but several of the participants commented that the task was extremely long and tedious, and they suggested that we provide some indication of participants’ progress across the task. Thus, for the second day of the experiment we amended the initiation of each trial so that it now indicated their progress (e.g., “Press space bar when ready (X/240)”, where X = trial number). The procedure was otherwise identical to the first day of the experiment.

Results

Outliers

Outlying response times more than 2.5 *SD*s from the mean, calculated separately for each participant and each condition, were removed from analyses (3.06% of trials). Response times from trials that elicited an error were also excluded from analyses (2.61% of trials). Additionally, one outlying participant whose overall mean error rate was more than 2.5 *SD*s beyond the group mean was excluded from all analyses (1.00% of participants). The analyses reported below thus were calculated across 99 participants.

Error rates

Error rates were analyzed via logistic mixed effects regression with participants and items as crossed random effects, with spatial association, target location, and their interaction as categorical predictors.[6] Only the effect of target location was significant, $B = -.26$, $t = 2.09$, $p = .04$, with more accurate responses when targets appeared at the bottom ($M = 2.94\%$) than at the top of the display ($M = 2.29\%$).

Response times

Response times were analyzed via linear mixed effects regression with participants and items as crossed random effects, with spatial association, target location, and their interaction as categorical predictors. A significant effect of target location indicated that responses were faster when targets appeared at the top ($M = 612$ ms) than at the bottom of the display ($M = 638$ ms), $B = -25.96$, $t = 6.13$, $p < .001$. Thus, top targets elicited faster but less accurate responses than bottom targets. This likely represents a speed-accuracy tradeoff, and indeed, target location did not reliably affect error rates or response times across experiments (see Online Supplemental Table). More importantly, the spatial association × target location interaction was also significant, $B = -15.26$, $t = 2.36$, $p = .02$. As shown in Fig. 3, top targets elicited faster responses after upward cues than downward cues, whereas bottom targets elicited faster responses after downward cues than upward cues. This spatial facilitation effect was small (7 ms) but significant.

Recall that the first half of participants received no feedback about their progress through the experiment, whereas the second half of participants were shown a progress bar indicating how many trials they had completed. Further analysis with this "half" variable included as an additional predictor, along with all possible interactions, yielded nearly identical results: The spatial association × target location interaction remained significant, $B = -15.27$, $t = 2.36$, $p = .02$, whereas the half factor failed to exhibit any effects or interactions, all $p > .29$.

Discussion

Experiment 2 revealed significant spatial facilitation with semantically matching targets. That is, "bird" elicited faster recognition of a bird at the top of a display than at the bottom. This experiment not only demonstrates spatial facilitation in a visual discrimination task, it also provides one of the first demonstrations of the reliability of web-based response time measurements in an attentional task of this sort (see also Crump, McDonnell, & Gureckis, 2013). This spatial facilitation of semantically matching targets supports a critical assumption of both the competition and the matching accounts. Next we attempted to discriminate between these two accounts.

Differentiating the accounts

The competition account and the matching account make differing predictions concerning spatial interference from cue words varying in *imageability*—that is, the ease with which a word evokes a perceptual representation. For generality, in addition to imageability, we also consider

[6] Models with the subject random-slope for the spatial association factor and the interaction did not converge, so the random slope was only fitted for target location. This choice did not alter the conclusions.

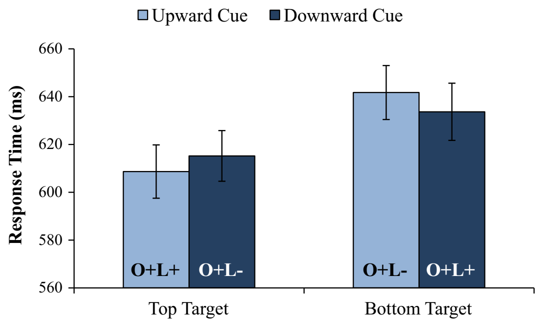

Fig. 3. Response times ($M \pm SE$) to semantically matching target objects presented at the top or bottom of a display following cue words with upward or downward associations, Experiment 2. Object (O) and location (L) codes are provided at the base of each bar.

abstract and concrete concepts. Imageability is strongly correlated with concreteness (Clark & Paivio, 2004; Friendly, Franklin, Hoffman, & Rubin, 1982; Paivio, Yuille, & Madigan, 1968; Reilly & Kean, 2007) and hence the two measures are often considered synonymous (Reilly & Kean, 2007; for review see Connell & Lynott, 2012; for a contrary view see Kousta, Vigliocco, Vinson, Andrews, & Del Campo, 2011).

If spatial interference is due to perceptual competition (Bergen et al., 2007; Estes et al., 2008; Richardson et al., 2003; Verges & Duffy, 2009), then highly imageable words should elicit more interference than words low in imageability, because highly imageable words by definition are more strongly perceptual than words low in imageability (Wiemer-Hastings & Xu, 2005). It must be noted, however, that this prediction may not emerge from all models of abstract concept representation. There is broad consensus that concrete, highly imageable concepts are represented primarily in terms of their sensorimotor features (e.g., Barsalou, 2008; Gallese & Lakoff, 2005; Kousta et al., 2011). Regarding the representation of abstract concepts, however, there currently is no consensus. The majority of researchers have proposed that abstract concepts are represented primarily in terms of the introspective and/or affective information acquired during prior experiences or situations of those abstract concepts (Barsalou & Wiemer-Hastings, 2005; Kousta et al., 2011; Pecher, Boot, & van Dantzig, 2011). By these models, abstract concepts are less perceptual than concrete concepts, and hence abstract concepts should elicit less spatial interference than concrete concepts. However, a more extreme model argues that abstract concepts are represented via conceptual metaphors (e.g., "love is a journey") that map the abstract concept (i.e., love) onto a sensorimotor source concept (i.e., journey; Gallese & Lakoff, 2005; Lakoff & Johnson, 1980; for review and critical evaluation see Pecher et al., 2011). Thus, by this conceptual metaphor theory, abstract concepts might alternatively be expected to elicit the same amount of spatial interference as concrete concepts. In general though, if spatial interference is due to perceptual competition from visual representations (i.e., the competition account), then highly imageable words should elicit more interference than words low in imageability.

In contrast, the matching account predicts that abstract, non-imageable cue words should elicit the same amount of interference as concrete, highly imageable words. This is because the target object and its location are both coded for their congruence with the cue word, even if that cue word's meaning and its spatial association are purely metaphorical. For example, upon seeing a picture of a liberal or conservative politician, one's attention respectively shifts leftward or rightward (Mills, Smith, Hibbing, & Dodd, 2015), and past tense and future tense verbs also respectively shift attention leftward and rightward (Ouellet, Santiago, Funes, & Lupianez, 2010). Thus, it is not necessary for the word to have a referent that actually physically occurs in the given location in order to elicit spatial effects. So long as the cue word has a spatial association, the to-be-identified visual target will be coded for its congruence with that cue. Consequently, even purely abstract words that lack a visual referent can induce spatial effects. Suppose "love", which has an upward spatial association, is followed by a square target at the top of the display. That visual target is unrelated to the cue word, so the codes are inconsistent (O− L+) and thus interference ensues. If that target instead appears at the bottom of the display, then the codes are consistent (O− L−) and hence responding should be faster. So unlike the competition account, the matching account predicts equivalent interference from cue words of high and low imageability.

Do abstract concepts elicit spatial interference?

Prior evidence concerning whether imageability (or concreteness) moderates the spatial interference effect is sparse and inconclusive. In their original demonstration of the spatial interference effect, Richardson et al. (2003) included both abstract and concrete sentences as spatial cues. Surprisingly, they found significant spatial interference from abstract sentences but not from concrete sentences (see their footnote 1). As pointed out by Bergen et al. (2007), however, Richardson et al.'s abstract sentences consisted of an abstract verb instantiated with concrete subject and object nouns (e.g., "The girl hopes for a pony"), thus likely rendering the sentences concrete rather than abstract. Bergen et al. therefore examined spatial interference from sentences that were more clearly concrete (e.g., "The mule climbed") or abstract (e.g., "The cost climbed"). In direct contrast to Richardson et al., Bergen et al. found spatial interference with concrete sentences, but no effect with abstract sentences. They concluded that abstract concepts do not evoke location-specific perceptual representations. More recently, both abstract and concrete words have been shown to elicit spatial interference at short delays between cue and target presentation, but instead elicit spatial facilitation at long delays (Goodhew, McGaw, & Kidd, 2014; Gozli et al., 2013).

However, the theoretical clarity and explanatory power of imageability and concreteness have recently been challenged (Connell & Lynott, 2012; Kousta et al., 2011). Although imageability and concreteness ratings are supposed to take into account all five sensory modalities, it is unclear to what extent a single imageability or concreteness value reflects each of the various modalities (Connell & Lynott, 2012), and in fact neither imageability nor concreteness ratings adequately reflect the full range of people's sensory experience of a concept (Connell & Lynott, 2012; Juhasz, Yap, Dicke, Taylor, & Gullick, 2011). Alternatively, several research groups have recently espoused the use of *perceptual strength* ratings collected separately for each modality (Amsel, Urbach, & Kutas, 2012; Lynott & Connell, 2009, 2012; van Dantzig, Cowell, Zeelenberg, & Pecher, 2011), and indeed a rapidly growing number of studies have shown that those perceptual strength ratings reliably predict a range of cognitive and linguistic behaviors such as word reading times, lexical decision times, property verification times, concreteness judgment times, and memory accuracy (Amsel et al., 2012; Connell & Lynott, 2010, 2011; Louwerse & Connell, 2011; Lynott & Connell, 2009; van Dantzig et al., 2011). In a particularly striking demonstration, Connell and Lynott (2012) showed that when the perceptual strength of each of the five modalities are rated separately, those perceptual strength ratings explain significantly and substantially more variance in word naming and lexical decision response times and error rates than do either imageability ratings or concreteness ratings, thus dramatically outperforming standard measures that were used in research for the prior 50 years.

To provide a stronger and more precise test of the competition account of spatial interference, we therefore examined the effect of *visual strength* (i.e., perceptual strength in the visual modality; Lynott & Connell, 2009, 2012) on target detection. The competition account concerns the visual modality in particular, so these visual strength ratings provide a more direct test of the hypothesis than any prior study. If spatial interference is due to visual competition, then words that elicit stronger visual representations (i.e., visually strong words) should elicit more spatial interference than visually weak words. Alternatively, if spatial interference were due to spatial coding (i.e., the matching account), then visually weak words should also induce spatial interference if they have strong spatial associations.

Experiments 3 and 4: Discriminating between accounts

We tested via the cueing paradigm whether visually strong and weak nouns (Experiment 3) and verbs (Experiment 4) elicit spatial interference. Our sample of cue words ($N = 256$) was considerably larger than prior studies. Visually strong (e.g., "bird") and visually weak (e.g., "love") cue words appeared one at a time in the center of a display, followed by an unrelated visual target (X or O) at the top or bottom of the display, and participants simply identified each target as X or O by keypress (as in Estes et al., 2008). For brevity, Experiments 3 and 4 are reported together as a between-participant manipulation of word class (nouns, verbs).

Methods

Participants

Undergraduates at Rutgers University-Camden participated in Experiments 3 ($N = 53$) and 4 ($N = 40$) for course credit. None participated in both experiments. An additional 52 participants from Mechanical Turk participated in a Visual Strength Pre-Test.

Stimuli

Stimuli were 256 cue words (see Appendixes B and C for a complete list of the 128 noun and verb cues, respectively). Many were sampled from prior studies on language and spatial attention (Bergen et al., 2007; Estes et al., 2008; Meteyard, Bahrami, & Vigliocco, 2007; Richardson et al., 2003; Verges & Duffy, 2009), and others were generated to vary in word class (nouns, verbs), spatial association (upward, downward), and visual strength (weak, strong). Stimulus properties are summarized in Table 1 and detailed below.

Spatial association

Spatial association ratings of the nouns were obtained from norms by Verges and Duffy (2009), who had participants rate the extent to which each word referred to an object typically associated with upward or downward locations (cf. Spatial Rating Pre-Test of Experiment 2). Spatial association ratings of the verbs were obtained from Meteyard and Vigliocco (2009), who had participants judge whether each word matched various spatial arrangements. We calculated spatial association scores by subtracting each verb's "down" score from its "up" score, so that higher scores indicated an upward association. Because the ratings of the nouns and verbs were collected via different methods and with different samples, they were *Z*-transformed within each class (nouns, verbs) and then combined. Thus, the spatial association values reported in Table 1 and Appendixes B and C are *Z*-scores, with higher values indicating upward associations and lower values indicating downward associations. Nouns and verbs both exhibited a large range of spatial associations with minimal skew, thus validating this factor for use in regression analyses.

Visual Strength Pre-Test

Fifty-two US-based participants were recruited from Mechanical Turk and were paid $0.75 for participating in a norming study of visual strength. Following Lynott and Connell (2012), visual strength was measured as "the extent to which you experience [word] by seeing" on a scale from 0 (not at all) to 5 (greatly). Each participant rated all 254 words ("flower" and "tower" appeared once as a noun and once as a verb in the experiment proper but appeared only once in the norming study) by clicking a radio button to the right of each word to indicate the selected rating. Word order was randomized within participants. The instructions emphasized that there were no right or wrong answers and encouraged participants to use the entire rating scale. To ensure that participants paid careful attention, we also included the six number words from "zero" to "five", and we instructed participants to select the response number indicated by the word (e.g., given "two", respond "2"). These attention checks appeared randomly throughout the list. Thirteen participants who failed this attention check (i.e., at least one incorrect response) were excluded from the study, leaving a valid sample of 39 participants.

As evident in Table 1, the visual strength scores exhibited good range with little skew, and so were appropriate for regression analyses. Thirty-eight of the words were also included in Lynott and Connell's most recent set of extended norms (personal communication). Our visual strength ratings correlated significantly with their visual strength ratings, $r = +.66$, $p < .001$, thus cross-validating the present ratings. Our visual strength ratings also correlated significantly with the spatial association scores ($r = -.28$, $p < .001$), such that visually weaker (abstract) concepts tended to have upward spatial associations. However, the weakness of this correlation indicated no problem of collinearity between the two predictors (Field, 2009). This noncollinearity was further supported in the main analysis of response times reported below, tolerance = .91 and VIF = 1.10.

Procedure

The procedure was very similar to Estes et al. (2008, Experiment 3), which was also similar to Experiment 1 reported here. Participants initiated each trial by pressing the space bar, which evoked a blank inter-stimulus interval (250 ms), followed by a central fixation (250 ms), a central cue word (100 ms), and another blank inter-stimulus interval (50 ms). Finally, a target appeared at either the top or bottom of the display and remained onscreen until the participant identified it as X or O via key press. Targets subtended approximately 1° of visual angle and appeared approximately 8° above or below the central fixation. Each cue appeared only once, with a randomly assigned Target Location (top, bottom) and Target Letter (X, O), such that each participant received equal numbers of top and bottom targets and X and O targets in each experimental condition. Thus there were 128 trials per participant. Trial order was randomized individually for each

Table 1
Spatial association scores and visual strength ratings of cue words in Experiments 3 and 4.

Word class	Factor	Min	Max	*M*	*SD*	Skew
Nouns (Expt. 3)	Spatial association	−1.76	2.39	0.00	1.00	0.35
	Visual strength	0.65	4.50	2.75	1.33	−0.15
Verbs (Expt. 4)	Spatial association	−2.02	2.01	0.00	1.00	−0.05
	Visual strength	0.67	4.50	2.19	0.75	0.24

Note: Spatial association values are *Z*-scores, with higher numbers indicating upward associations. Visual strength values are ratings on a scale from 0 to 5, with higher numbers indicating greater visual strength.

participant, and participants completed ten practice trials prior to the experimental trials.

Results

Outliers

Four items with mean response times more than 2.5 *SDs* beyond the overall mean were excluded (1.56% of items), thus leaving 252 items in total. Additionally, two outlying participants whose overall mean error rate was more than 2.5 *SDs* beyond the group mean were excluded from all analyses (2.15% of participants). The analyses reported below thus were calculated across 52 and 39 participants in Experiments 3 and 4 respectively. Response times from trials that elicited an error were excluded from analyses (5.62% of trials). Outlying response times more than 2.5 *SDs* from the mean, calculated separately for each participant and each condition, were also removed from analyses (0.79% of trials).

Error rates

Errors were analyzed via logistic mixed effects regressions[7] with participants and items as crossed random effects, with word class (nouns, verbs) and target location (top, bottom) as categorical predictors, with spatial association and visual strength as continuous predictors, and with all possible interactions included. Only the main effect of spatial association was significant, $B = -.11$, $t = 2.04$, $p = .04$: As spatial associations increased (i.e., toward upward associations), error rates decreased.

Response times

Response times were analyzed via linear mixed effects regression with participants and items as crossed random effects, with word class (nouns, verbs) and target location (top, bottom) as categorical predictors, with spatial association and visual strength as continuous predictors, and with all possible interactions included. The main effect of spatial association was significant, $B = -3.29$, $t = 2.08$, $p = .04$, such that faster responses were elicited by words with an upward spatial association. More importantly, the critical interaction of spatial association and target location was significant, $B = 15.20$, $t = 4.79$, $p < .001$. As in prior studies (Bergen et al., 2007; Estes et al., 2008; Gozli et al., 2013; Verges & Duffy, 2009), words with upward spatial associations elicited slower responses to top targets and faster responses to bottom targets. This relationship is illustrated in Fig. 4. For each unit increase in the cue word's spatial association (i.e., 1 *SD*, because units are *Z*-scores here), visual targets were identified 4 ms more slowly at the top and 14 ms more quickly at the bottom. In the extreme, words with spatial associations of −2 (e.g., "fall") and +2 (e.g., "arise") thus differed by about 50 ms in target identification at the bottom location. The 3-way spatial association × target location × visual strength interaction was not significant, $p = .40$, revealing no moderation of the spatial interference effect by visual strength. Indeed the identical pattern of results was also observed within both experiments separately, with a significant spatial association × target location interaction [Experiment 3[8]: $B = 15.47$, $t = 3.26$, $p = .001$; Experiment 4: $B = 14.91$, $t = 3.65$, $p < .001$] but no moderation by visual strength (both $p > .34$). Thus, spatial interference was obtained within and across the two experiments, and in neither case was it moderated by visual strength.

Visual strength

Given that visual strength failed to predict target identification times, we sought to validate the visual strength ratings by testing whether they predict lexical decision times (Connell & Lynott, 2012; Connell & Lynott, 2014), which were retrieved from E-Lexicon (Balota et al., 2007). We conducted a stepwise regression with lexical control factors of word length (number of letters), word frequency (log transformed; Brysbaert & New, 2009), and contextual diversity (i.e., the number of contexts in which a word appears; log transformed; Adelman, Brown, & Quesada, 2006) in the first step, and then we added visual strength ratings in a second step, with lexical decision times (log transformed) as the criterion. The initial model with control factors was significant, $R^2 = .41$, $F(3,248) = 56.45$, $MSE = .01$, $p < .001$, with significant effects of length ($\beta = .15$, $t = 2.82$, $p = .005$) and contextual diversity ($\beta = -.92$, $t = 3.12$, $p = .002$) but not frequency ($p = .23$), as is typical of word recognition studies (e.g., Adelman et al., 2006). More importantly for our purposes, the addition of visual strength ratings in the second model explained a significant amount of unique variance beyond those control factors, $\Delta R^2 = .01$, $F(1,247) = 4.51$, $\beta = -.11$, $p = .04$: As in prior studies (Connell & Lynott, 2012, 2014), strongly visual words elicited faster lexical decisions than weakly visual words. Thus, the failure of visual strength to predict target identification times was not attributable to an inadequacy of the visual strength ratings.

Imageability

We also tested whether the more general perceptual factor of imageability, rather than visual strength in particular, moderated the spatial interference effect. Imageability ratings of the cue words were retrieved from several sources (Bird, Franklin, & Howard, 2001; Clark & Paivio, 2004; Cortese & Fugett, 2004; Friendly et al., 1982; Schock, Cortese, & Khanna, 2012; Toglia & Battig, 1978), each of which used a 1 (low) to 7 (high) scale. Imageability ratings were available for 250 of the cue words. Nouns (range = 2.58–6.44; skew = −.48) and verbs (range = 1.78–6.05; skew = −.22) both exhibited a large range of imageability with minimal skew. Moreover, imageability was noncollinear with spatial association (tolerance = .94 and VIF = 1.07), thus indicating its appropriateness for regression analysis. We therefore replicated

[7] No crossed random-effects model would converge, so separate random-subjects and random-items analyses were performed, with matching results (also matching unconverged estimates).

[8] For the analysis of Experiment 3 only, to achieve convergence, several random slopes with respect to subjects were dropped: those that were retained were the target location × spatial association interaction (to ensure that the test of the critical effect did not have inflated alpha level) and the visual strength main effect. Taking the unconverged model fit would lead to the same substantive conclusions as to significance.

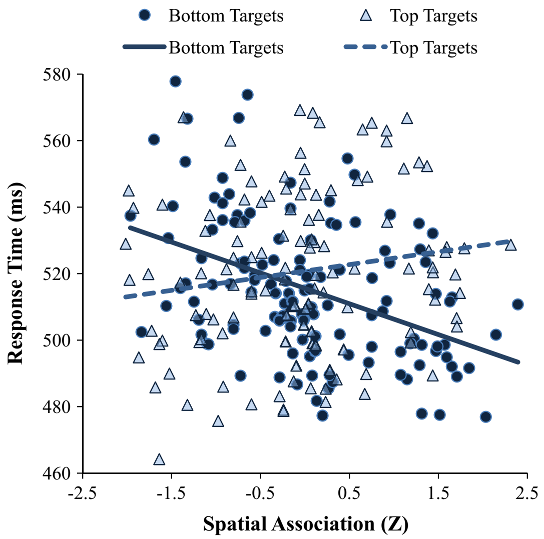

Fig. 4. Mean response times to visual targets presented at the top or bottom of the display as a function of the cue word's spatial association, Experiments 3 and 4. Higher and lower spatial association values indicate upward and downward associations, respectively. In terms of object (O) and location (L) coding, upward cues with top targets (i.e., right side of dashed line) and downward cues with bottom targets (i.e., left side of solid line) represent O– L+ trials, whereas upward cues with bottom targets (i.e., right side of solid line) and downward cues with top targets (i.e., left side of dashed line) represent O– L– trials.

the preceding linear mixed effects model, but with imageability replacing visual strength; the random slopes had to be excluded for both the two-way interactions involving imageability. Only the critical spatial association × target location interaction was significant, $B = 13.91$, $t = 3.97$, $p < .001$. No effect or interaction of imageability was significant, including the spatial association × target location × imageability interaction, $p = .50$. The spatial association × target location interaction indicating spatial interference was also significant within both experiments separately [Experiment 3: $B = 13.78$, $t = 2.59$, $p = .01$; Experiment 4[9]: $B = 14.27$, $t = 3.37$, $p < .001$], whereas the 3-way interaction indicating moderation by imageability did not approach significance within either experiment (Experiment 3: $p = .77$; Experiment 4: $p = .31$). The spatial interference effect thus was not moderated by imageability.

Testing alternative models of spatial coding

The observation of equivalently large spatial interference effects among visually strong and visually weak cue words in Experiments 3 and 4 fails to support the competition account, which has been the assumed explanation in prior studies of the spatial interference effect. Rather, the occurrence of a large spatial interference effect from visually weak cues supports instead the perceptual matching account. Below we consider two basic models of spatial coding, which we then test with the data from Experiments 3 and 4. For the remainder of this section of the paper, please keep in mind that we are referring to the interference paradigm in which the target was never related to the cue word (i.e., all targets were O–).

A categorical model of spatial coding

The typical experimental design, which contrasts cue words with upward (e.g., "star") or downward (e.g., "cellar") spatial associations (e.g., Bergen et al., 2007; Chasteen, Burdzy, & Pratt, 2010; Dudschig, Lachmair, de la Vega, De Filippis, & Kaup, 2012; Dudschig et al., 2013; Estes et al., 2008; Goodhew et al., 2014; Gozli et al., 2013; Quadflieg et al., 2011; Richardson et al., 2003; Verges & Duffy, 2009; Zhang et al., 2013), maps clearly onto the perceptual matching account described in the introduction: The visual target was described as appearing in either the "matching" location or a "mismatching" location. Thus, our theoretical conceptualization treated the congruence between the spatial association of the cue and the physical location of the target as a categorical factor. However, because our analyses of Experiments 3 and 4 used linear regression, those analyses did not provide a direct test of this categorical model of spatial coding.

If spatial coding were categorical, then we should observe the empirical hallmarks of a categorical effect: (1) within-category equivalence, and (2) between-category discontinuity. To illustrate, consider five cue words of vertically decreasing spatial associations: "star" = 6.23, "palace" = 5.05, "tree" = 4.00, "lawn" = 2.82, and "cellar" = 2.27 (where 1 = extremely low and 7 = extremely high). If spatial coding were categorical, then extremely and moderately upward cues (e.g., "star" and "palace") should both be coded as matching locations for a top target (L+), and thus they should elicit approximately equivalent interference effects for unrelated targets (O–), because both would elicit incongruent codes (O– L+). Likewise, moderately and extremely downward cues (e.g., "lawn" and "cellar") should both be coded as mismatching locations (L–), and should thus elicit equivalently fast responding to unrelated targets (O–) due to their equivalently congruent codes (O– L–). This is *within-category equivalence*. Moreover, at some point along the spatial association scale, the spatial coding must switch from matching to mismatching. This transitional range, which presumably includes spatially neutral cues like "tree", produces a *between-category discontinuity*. Thus, the categorical model of spatial coding predicts a nonlinear step-function between spatial associations and response times (see Fig. 5A, which is explained more fully below).

A graded model of spatial coding

The cue-target spatial relationship can be conceptualized alternatively as a continuum that ranges from complete congruence to complete incongruence. In fact, if spatial coding is graded in this way, then we may observe differing degrees of interference across the range of cue-target spatial congruence, in an approximately linear fashion. This prediction of graded interference can be understood in terms of the physical distance between the expected location (i.e., based on the cue's spatial

[9] For the Experiment 4 only analysis with imageability, from the random-items component, either the intercept or the random slope for target location had to be dropped to achieve convergence; the results are numerically indistinguishable.

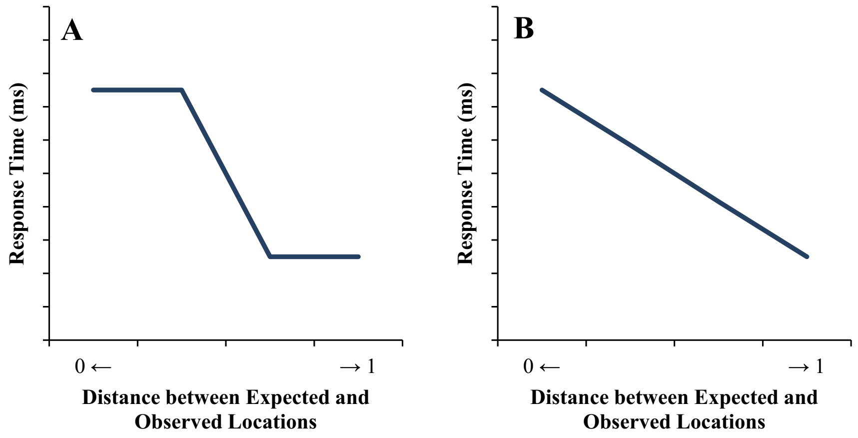

Fig. 5. Predictions of a categorical model (Panel A) and a graded model of spatial coding (Panel B). In terms of object (O) and location (L) coding, the left end of the *X*-axis represents O− L+ trials, and the right end represents O− L− trials.

association) and the observed location (i.e., the actual target location), with the magnitude of spatial interference being negatively proportional to the distance between expected and observed locations. Consider the example of "star", which has an extreme upward association. When an unrelated object appears at the top of the display, the object code is fully mismatching but the location code is fully matching, thereby producing fully inconsistent codes and hence a full interference effect. But now consider "tree", which has a neutral spatial association. When an unrelated object appears at the top of the display, the object code remains fully mismatching but now the location code is only semi-matching, so the object and location codes are only semi-consistent and hence the interference effect is attenuated. So as the distance between the actual location (e.g., at the top of the display) and the expected location gradually increases across intermediate spatial cues like "palace", "tree", and "lawn", spatial interference should gradually diminish. And finally, with an extremely downward association (e.g., "cellar"), the distance between expected and observed locations is maximal, the object and location codes are fully consistent (O− L−), and hence the spatial interference is minimized. Thus, the graded model predicts a linear relation between spatial associations and response times. To be clear, this graded model of spatial interference is entirely consistent with the theoretical descriptions presented in the introduction. The graded model simply fills in the theoretical gap between the extreme cases used in standard experimental designs (e.g., Experiments 1 and 2 above).

Methods

Using the data from Experiments 3 and 4, we tested whether the spatial interference effect is categorical or graded. Our predictor variable was the *distance between the expected and observed locations* of the target object, and the criterion variable was response time. Distance scores were computed via the following procedures. First we re-scaled the spatial association ratings for the cue words, setting the lowest rating as 0 and the highest rating as 1. This value represents the *expected location*. Then we simply coded the target locations as 0 for bottom targets and 1 for top targets. This value represents the *observed location*. Finally we calculated the absolute value of the difference between those expected and observed locations, so that low values indicate that the target appeared at or near its expected location, and high values indicate that the target appeared far from its expected location. Taking the absolute value allowed us to collapse across top and bottom targets. For instance, "sky" elicited one of the highest spatial association ratings, so its expected location was near 1, at .95. When the target appeared at the top location (i.e., observed location = 1), the distance between expected and observed locations was minimal (i.e., $|.95 - 1| = .05$). And conversely, "fail" elicited one of the lowest spatial association ratings (i.e., expected location = .01), so when the target appeared at the top location (i.e., observed location = 1), the distance between expected and observed locations was large (i.e., $|1 - .01| = .99$).

The predictions of the categorical and graded models of spatial coding are illustrated in Fig. 5A and B, respectively. If spatial coding is categorical (Fig. 5A), then targets appearing extremely or moderately near the expected location should elicit equally slow responses, and targets appearing extremely or moderately far from the expected location should elicit equivalently fast responding. Alternatively, if spatial coding is graded (Fig. 5B), then response times should gradually decrease as the distance between expected and observed locations increases.

To test whether the spatial interference effect was categorical or graded, we compared linear and nonlinear models using restricted cubic splines. Restricted cubic splines are an alternative to the better-known polynomial regression. Both methods flexibly produce nonlinear functions of the predictor by introducing several transformations of that predictor into the linear regression (in the polynomial case, these are the original predictor, the square of the predictor, the cube of the predictor and so on), each with its own regression coefficient. Restricted cubic splines are often preferred to polynomial regression because their fits are considered more flexible and more plausible. With restricted cubic splines, the fitted function in one part of the predictor range is not strongly influenced by the fitted function in another part of the predictor range, as the function can be considered as a series of segments that are joined (smoothly) at pre-defined values (known as knots) of the predictor. The two end segments are linear, and all interior segments are cubic (hence the name). In contrast, with polynomial regression, a small change in the middle of the range can massively change the function at the end of the range (and the extrapolation beyond the range), producing visually bizarre fits. That is, unlike polynomial regression, restricted cubic splines can produce sigmoid functions that flatten at the ends of the range.

Restricted cubic splines with 5 knots in distance were fitted (at default locations: 5%, 27.5%, 50%, 72.5%, 95% quantiles[10]), with random slopes for the linear effect only,[11] because (a) the model would not converge with random slopes for each component of the spline, and (b) this maintained consistency with the linear model, which was fitted with these random slopes. Unlike with polynomial regression, the nonlinear components of restricted cubic splines are not orthogonal to the linear component nor each other. We thus used model comparison to determine whether the nonlinear model fits better than the linear model, to test whether the nonlinear block is significant, rather than examining the regression coefficients (whose collinearity removes all power).

Results

When fitted alone, the linear effect of distance between expected and observed locations was significant, $B = -25.87$, $t = -4.11$, $p < .001$. Adding the nonlinear block did not significantly improve the fit of the model, $\chi^2(3) = 1.08$, $p > .7$. Thus, the spatial interference effect varied approximately linearly with the distance between the expected and observed target locations. That is, the smaller the distance between expected and observed target locations, the larger the magnitude of the spatial interference effect (see Fig. 5B). The linearity of this effect suggests that spatial coding is graded rather than categorical.

General discussion

Experiments 1 and 2 tested the basic assumption that the direction of linguistic cueing effects is moderated by the semantic relation between the cue and target. When the target semantically *mismatched* the cue (e.g., "bird" followed by an image of a wrench), that target object was recognized significantly more *slowly* at the cue word's associated location (i.e., at the top) than at the opposite location (i.e., at the bottom). That is, semantically unrelated targets elicited the spatial interference effect (Bergen et al., 2007; Estes et al., 2008; Gozli et al., 2013; Richardson et al., 2003; Verges & Duffy, 2009). When the target semantically *matched* the cue (e.g., "bird" followed by an image of a bird), however, that target was instead recognized more *quickly* at the cue's associated location (i.e., at the top) than at the opposite location (i.e., at the bottom). That is, semantically related targets elicited a spatial facilitation effect (Fig. 3). Experiments 3 and 4 revealed that strongly visual and weakly visual nouns and verbs (e.g., "bird", "arise") hindered identification of unrelated visual targets (X or O) at their associated location (i.e., upper visual field; Fig. 4), thereby replicating the spatial interference effect (Bergen et al., 2007; Estes et al., 2008; Gozli et al., 2013; Richardson et al., 2003; Verges & Duffy, 2009) and extending it to visually weak words. Spatial associations predicted target identification times in an approximately linear manner (Fig. 5B), whereas visual strength failed to predict identification times. Below we discuss the empirical contributions of this research and its theoretical implications for the competition and matching accounts of spatial interference.

This research provides several empirical contributions. To begin with, Experiments 1 and 2 provided the first evidence that the semantic relation of the cue and target strongly moderates the spatial effect, with interference from mismatching targets but facilitation from matching targets. Experiment 1 further indicated that object matches (O+) had a far larger impact on object recognition than location matches (L+). That is, responding was faster when the cue's referent was present than it was absent. Experiments 3 and 4 also used many more stimuli ($N = 256$) than prior studies, thereby demonstrating the generality of spatial interference. Moreover, the effect occurred with both noun and verb cue words (see also Verges & Duffy, 2009), and with both abstract and concrete cue words (see also Gozli et al., 2013). This latter contribution is theoretically informative (as described below), and contrasts with prior results of Bergen et al. (2007), who found spatial interference with concrete sentences (e.g., "The mule climbed") but not with abstract sentences (e.g., "The cost climbed"). We cannot say with any certainty why our results differ from those of Bergen et al., but it may be due to the fact that their stimuli were varied on concreteness, whereas ours were varied on visual strength (in addition to imageability). This difference in fact highlights another empirical contribution of this research: Our use of visual strength ratings is methodologically superior to the use of imageability or concreteness ratings, which are substantially less predictive of language processing (Connell & Lynott, 2012). Finally, our results provide the first demonstration that the spatial interference effect is linear. Whereas all prior studies have simply contrasted words of extremely upward or downward spatial associations, our results revealed that the spatial interference effect decreases gradually as the physical distance between the expected and observed target locations increases.

Perceptual competition

Many researchers have attributed the spatial interference effect to location-specific perceptual representations: The word "bird" shifts attention upward and evokes the

[10] With modified knot placement to permit steeper sigmoid functions (0.05, 0.45, 0.5, 0.55, 0.95 values of the distance parameter), the qualitative conclusion did not change.

[11] If anything, this should increase our power to detect the nonlinear effect.

perceptual representation of a bird, which impairs identification of the visual target (e.g., "O") either by visually masking the target or by preoccupying the neural systems necessary for visual perception (Bergen et al., 2007; Estes et al., 2008; Richardson et al., 2003; Verges & Duffy, 2009). However, the present results failed to support this explanation. If spatial interference were due to visual competition, then words with strongly visual representations (e.g., "bird") should elicit greater interference than words with weak or nonvisual representations (e.g., "freedom"). But instead, words of strong and weak visual strength and high and low imageability elicited equivalent interference. This counter-evidence was observed in two experiments with a large number of noun and verb cue words, as well as across both experiments combined.

One possible defence of the competition account is that our ratings of visual strength were somehow flawed and hence our independent variable was invalid. This suggestion is unlikely to be correct, because our visual strength ratings did significantly predict word recognition times, thereby replicating prior studies (Connell & Lynott, 2012, 2014). So our measures and variables appear to be reliable and valid. Another possible defence of the competition account is that visual strength ratings are epiphenomenal and do not actually reflect perceptual representations. This suggestion is also unlikely to be correct, as perceptual strength ratings do predict actual perceptual judgments (Connell & Lynott, 2010; see also van Dantzig, Pecher, Zeelenberg, & Barsalou, 2008) and related perceptual phenomena such as the modality switch effect (Connell & Lynott, 2011; Lynott & Connell, 2009; van Dantzig et al., 2011).

Yet another defence is that our prediction for the competition account is infelicitous. That is, one could argue that the competition account actually predicts equivalent interference from strongly visual and nonvisual words. For instance, the conceptual metaphor theory claims that abstract concepts are represented in terms of an analogous sensorimotor concept (e.g., "love is a journey"; Gallese & Lakoff, 2005; Lakoff & Johnson, 1980). So to the extent that the source concept (e.g., journey) is visual, the abstract concept (i.e., love) should elicit the same amount of spatial interference. More common, however, is the claim that abstract concepts are represented primarily in terms of introspection (Barsalou & Wiemer-Hastings, 2005; Pecher et al., 2011) or emotion (Kousta et al., 2011). Assuming that introspective information (e.g., recalling an experience of being in love) and affective information (e.g., the state of arousal evoked by being in love) are less visual than concrete objects such as birds and grass, these models predict that abstract concepts should elicit less spatial interference than concrete concepts. Notably, our cue words ranged from 0.65 to 4.50 on the 0-to-5 visual strength scale, so it is not the case that our stimulus set lacked cue words with sufficiently weak visual representations. If spatial interference were due to visual competition, then surely strong visual words like "sky" and "jump" should elicit more interference than nonvisual words like "heaven" and "flourish", but they did not.

Thus, we found no evidence that perceptual competition explains the spatial interference effect. Before considering the perceptual matching explanation, let us be clear that these results do not imply a general rejection of perceptual representation or perceptual simulation. A great many behavioral and neuropsychological studies have conclusively demonstrated the activation of perceptual representations during language processing (Barsalou, 2008). Presumably, perceptual representations are also activated in the linguistic cueing paradigm; the present results simply indicate that such perceptual representations are not the theoretical culprit causing the spatial interference effect.

Perceptual matching

The spatial interference effect is explicable instead by an account based on the perceptual match between the cue word and the visual target. This account assumes that linguistic cues elicit a visual search for the cue's referent, even though the cue's referent is often absent (Dahan & Tanenhaus, 2005; Richardson & Spivey, 2000; Spivey & Geng, 2001). This account further assumes that target objects and locations are both coded for their match with the cue word in order to establish whether the target is related to the cue. Critically, consistent object and location codes unambiguously indicate whether the target is related to the cue, and therefore they elicit relatively fast responding. In contrast, inconsistent codes provide conflicting evidence about the target's relation to the cue, and hence they elicit further processing and slower responding. To illustrate, after hearing or reading "bird", an unrelated visual target (e.g., "O") elicits inconsistent codes at a top location (O− L+) but consistent codes at a bottom location (O− L−). So paradoxically, even though the bottom target is both an unrelated object and an unassociated location, the consistency of those negative codes is unambiguous and thus allows the observer to proceed with the task of identifying what the target actually is. And despite the top target appearing in the associated location, this hinders responding because the object and location codes are inconsistent, thereby requiring additional processing to disambiguate the target's relation to the cue before identifying what the target actually is. This account can explain not only the prior demonstrations of spatial interference from visually strong cue words, but also our novel demonstration of spatial interference from visually weak cue words such as "love". Because the visual target was unrelated to "love", it elicited inconsistent codes at its associated upper location (O− L+), thus delaying the response. This account is also plausible more generally because (1) linguistic cues do elicit a visual search for the cue's referent (Altmann & Kamide, 2007; Spivey et al., 2001), (2) objects and locations are indeed coded independently in perception (Ungerleider & Haxby, 1994), and (3) the consistency between codes does indeed influence cognitive judgments (Lu & Proctor, 1995).

We also tested whether spatial coding is categorical or graded. By a categorical model, each target is coded as either spatially "matching" or "mismatching" (see Fig. 5A). The graded model instead posits that the degree of spatial interference is negatively proportional to the physical distance between the expected (i.e., associated) and observed (i.e., actual) target locations. Consequently, given a target appearing at the top location, identification times should be slowest following cues with extremely upward associations, and should decrease gradually across cues with neutral and downward spatial associations. The results supported this prediction of an approximately linear spatial interference effect. So to be clear, our descriptions of targets as being spatially "matching" or "mismatching" is a conceptual simplification of our actual results, which instead revealed that spatial congruence is a matter of degree. Our terminology of L+ and L− only represents the endpoints of this spatial congruence continuum, which also includes moderately congruent and incongruent cues as well as spatially neutral cues.

Accounting for spatial interference and facilitation

The perceptual matching account also explains spatial facilitation. When the target object semantically matches the cue word (e.g., "bird" followed by an image of a bird), its recognition is fast, as shown by the large main effect of target object in Experiment 1. This simple observation follows naturally from the assumption that linguistic cues elicit a visual search for the cue's referent. As soon as that object is located, target identification is complete. In contrast, if the cue's referent is absent, then the observer must begin the process of identifying what object the target actually is, and of course this second attempt at target identification delays responding. Moreover, when the cue's referent is present, its location also affects its recognition time. "Bird" shifts visual attention upward, and if an image of a bird is present there, then both the object and location codes are positive (O+ L+) and hence identification is complete. But if the bird image is instead at the bottom of the display, then the perceptual evidence is ambiguous (O+ L−), thereby slightly delaying the target's recognition. Thus, perceptual matching can explain both interference and facilitation from linguistic cues.

Although we found both interference in mismatching targets and facilitation in matching targets, the interference effect was about twice as large (17 ms in Experiment 1) as the facilitation effect (10 and 7 ms in Experiments 1 and 2 respectively). We suspect that this differential effect size, if it is reliable, may simply be due to the overall longer response times to mismatching targets. As shown in Fig. 2, responses were 47 ms slower on average to mismatching targets than to matching targets. And critically, conditions that elicit slower response times typically exhibit larger effects in absolute terms (ms), but not necessarily in relative terms (e.g., % difference). Indeed, in Experiment 1 the mismatching targets elicited a 3% slowdown in responding (i.e., effect size/mean RT = 17/563 = 3%), whereas the matching targets elicited a 2% speed up in responding (i.e., 10/516). The interference and facilitation effects thus do not appear to differ substantially in magnitude.

In fact, even when the cue and target are semantically unrelated, the graded conceptualization of spatial coding suggests that the term "spatial interference effect" may be a misnomer, in that the effect of a cue word's spatial association on recognition times may be either facilitation (on O− L− trials) or interference (on O− L+ trials). That is, if we consider spatially neutral cue words as a sort of baseline, then spatially consistent trials do indeed exhibit interference, but spatially inconsistent trials actually exhibit facilitation. The linear nature of the effect means that while it is true that O− L+ cues slow recognition, it is also true that O− L− cues speed recognition, relative to spatially neutral cue words. This observation of both interference and facilitation within a single linguistic orienting task with identical procedural parameters has not previously been possible, because all prior studies have only compared spatially consistent and inconsistent trials. By additionally including spatially neutral cue words in our analyses, we were able to test for and observe both spatial interference and facilitation from semantically unrelated targets. And as explained above, this observation critically discriminated between two plausible models, thus providing a more clearly specified model of spatial effects than prior studies.

We believe that our matching account may also explain some additional results in the literature that otherwise are difficult to integrate theoretically with the spatial interference effect: The matching account may explain the task-sensitivity of linguistic orienting effects more generally. To our knowledge, all prior demonstrations of spatial interference (Bergen et al., 2007; Estes et al., 2008; Gozli et al., 2013; Richardson et al., 2003; Verges & Duffy, 2009) required participants to identify a target stimulus. In contrast, a few recent studies have used a detection task instead, whereby participants simply pressed a button as soon as they detected the presence of a visual target (regardless of its identity). Interestingly, those studies found that spatial cue words *facilitated* target detection at their associated location (Chasteen et al., 2010; Dudschig et al., 2012; Gozli et al., 2013). The matching account may also explain this facilitated target detection, in that the detection task may not elicit an object code because the target's identity is not relevant to responding. Suppose "bird" is followed by a square target at the top of the display in a detection task. The target appears in the congruent location, and because the task does not entail object coding, the congruent location code simply produces facilitation. In other words, because the target location is coded but the target object is not coded, inconsistent codes do not arise and hence the congruent location code facilitates responding. This explanation assumes, however, that object and location codes are activated in a task-sensitive manner. For instance, the object code is relevant in the present experiments precisely because the task is to recognize the target object. However, target recognition is not required in the detection task, so the object code is not relevant to the task. Accumulating evidence supports this assumption that object and location coding may be task-sensitive (Brookshire, Ivry, & Casasanto, 2010; Lebois et al., in press), so this account of task-sensitive interference and facilitation appears plausible.

Future directions

A potentially interesting direction for further research is to develop a deeper understanding of spatially neutral concepts. There is a fundamental ambiguity of "neutral" spatial association ratings, at or near the scale midpoint: A mid-scale rating could truly indicate spatial *neutrality* (i.e., the referent is expected to occur at a vertically central location), or it could alternatively indicate spatial *unpredictability* (i.e., the referent is expected to occur at various locations on the vertical dimension), or spatial *irrelevance* (i.e., vertical location is not a relevant property of the referent). The present research does not distinguish between these different types of neutral spatial associations, but they may well yield different results in other paradigms. For instance, spatial neutrality might facilitate a central fixation focus, whereas spatial unpredictability might instead elicit random visual search, and spatial irrelevance might not affect attention allocation at all. We believe that empirical discrimination of these types of spatial neutrality could provide additional theoretical insights.

Another important area for further research is to examine more finitely the semantic relation between the cue word and target object. In our experiments, the visual target was either an image of the object denoted by the cue word (e.g., "bird" followed by a bird image), or a completely unrelated object (e.g., "bird" followed by a wrench image) or target letter (e.g., "bird" followed by X). Would a semantically-related-but-mismatching target (e.g., "bird" followed by an airplane image) elicit facilitation from semantic priming, or might it elicit interference due to a sort of lateral inhibition? The present experiments are unable to address this question, but its answer will provide a more sophisticated model of this sort of linguistically mediated visual search. To be sure, the pattern of spatial interference and facilitation effects in the identification and detection tasks is complex (see Gozli et al., 2013), but a perceptual matching account provides a promising direction for further theoretical development.

Acknowledgments

We thank Sean Duffy for assistance with data collection and theoretical discussion during the early stages of this research. The first author (Z.E.) gratefully acknowledges the generous support of the Center for Research on Marketing & Services (CERMES) at Bocconi University.

Appendix A

Results of the spatial rating pre-test of Experiment 2. Cues selected for use in the experiment are identified in the "Cue Category" column.

Cue	Spatial association	% Nowhere	Cue Category	Cue	Spatial association	% Nowhere	Cue Category
alligator	1.48	6	Downward	kite	4.23	6	Upward
anchor	1.34	14	Downward	knee	2.13	3	
angel	4.64	47		ladder	3.46	16	
ant	1.22	7	Downward	lake	1.67	3	
antenna	3.79	16	Upward	lamp	2.74	18	
arrow	3.20	46		lawn	1.37	2	
asteroid	4.78	7		lightbulb	3.73	20	
attic	3.97	2		lightning	4.56	4	Upward
badge	2.81	12		loft	3.72	5	
banana	2.80	56		mask	3.08	11	
basement	1.33	5		mat	1.34	5	
beach	1.80	6		meteor	4.90	4	
beanstalk	3.11	12		mirror	2.94	12	
beaver	1.64	9	Downward	missile	4.65	18	
bed	2.26	1		moat	1.54	7	
beetle	1.31	14	Downward	mole	1.42	10	
bell	3.31	42		moon	4.90	2	Upward
belt	2.41	9		mountain	4.39	5	Upward
bike	2.31	5		mouse	1.24	8	Downward
bird	4.11	15	Upward	mustache	2.99	4	
blimp	4.75	4	Upward	necklace	3.02	6	
book	2.68	41		nest	3.93	11	Upward
bowtie	2.98	7		ocean	1.70	4	
branch	3.84	15	Upward	parachute	4.44	16	Upward
bridge	3.14	10		parrot	3.32	28	
bullet	2.76	54		patio	2.18	7	
cabinet	3.14	9		phone	2.68	29	

(*continued on next page*)

Appendix A (*continued*)

Cue	Spatial association	% Nowhere	Cue Category	Cue	Spatial association	% Nowhere	Cue Category
candle	2.58	34		pier	2.27	5	
car	2.60	2		pig	1.79	3	
carpet	1.31	2		plane	4.70	7	Upward
carrot	1.58	35		planet	4.91	11	Upward
casket	1.83	12		pool	1.59	4	Downward
cat	1.67	18		porch	2.21	5	
cave	2.50	16		poster	3.15	13	
ceiling	3.97	2		potato	1.73	37	
cellar	1.38	4		puddle	1.33	3	Downward
cemetery	1.71	7		rainbow	4.58	4	Upward
chair	2.36	3		river	1.57	3	
chandelier	3.98	2	Upward	road	1.55	2	Downward
chicken	1.56	11	Downward	rock	1.40	18	
chimney	3.97	4	Upward	roof	4.09	1	Upward
chin	2.93	4		sandals	1.36	5	Downward
cigarette	2.88	31		satellite	4.79	5	Upward
clock	3.37	21		scarf	3.00	12	
cloud	4.76	1	Upward	sea	1.68	6	
collar	2.87	7		sewer	1.20	2	
comet	4.88	4	Upward	sheep	2.02	2	
crown	3.34	8		shirt	2.83	10	
crypt	1.69	10		shoes	1.40	3	Downward
cuckoo	3.25	29		sink	2.38	4	
cup	2.64	34		skateboard	1.48	5	Downward
curtains	3.21	5		skates	1.41	9	Downward
dart	2.92	34		skis	1.62	13	Downward
desk	2.40	0		skylight	4.09	1	
devil	1.64	53		skyscraper	4.61	2	Upward
dirt	1.23	6		sled	1.64	9	Downward
door	3.01	4		slippers	1.35	6	Downward
duck	1.74	18		slug	1.22	8	Downward
dungeon	1.41	12		snail	1.16	4	Downward
ear	3.06	3		socks	1.45	6	Downward
elbow	2.62	7		sofa	2.24	3	
elephant	3.47	7		star	4.94	2	Upward
eye	3.03	3		steeple	3.96	4	Upward
feet	1.31	2	Downward	stork	3.64	14	Upward
fireworks	4.62	3	Upward	sun	4.77	2	Upward
fish	1.32	12	Downward	surfboard	1.81	23	
flag	3.97	7	Upward	table	2.43	0	
flower	1.54	13	Downward	telescope	2.91	14	
flute	2.86	35		television	2.91	7	
fork	2.45	38		tiara	3.22	6	
frisbee	3.35	32		toes	1.36	3	
frog	1.32	10	Downward	toilet	1.98	2	
giraffe	3.84	4	Upward	tooth	2.99	7	
glasses	3.07	11		tornado	4.04	17	
gopher	1.25	5	Downward	towel	2.70	37	
grass	1.28	3	Downward	tower	4.36	2	Upward
grave	1.29	3		trail	1.59	5	
grill	2.46	5		train	2.96	5	
guitar	2.59	20		tree	3.67	5	Upward
gun	2.64	41		trousers	2.19	9	
halo	3.52	15		turban	3.23	10	
harbor	2.07	10		vase	2.59	21	

Appendix A (*continued*)

Cue	Spatial association	% Nowhere	Cue Category	Cue	Spatial association	% Nowhere	Cue Category
hat	3.29	9		volleyball	3.06	48	
head	3.09	1		weeds	1.45	4	Downward
helicopter	4.62	2	Upward	well	1.53	3	Downward
helmet	3.16	8		whale	1.67	9	Downward
horse	3.02	3		wheel	1.76	7	
house	3.15	2		wig	3.18	10	
hurricane	3.91	31		window	3.01	13	
jacket	2.87	17		worm	1.13	4	Downward

Appendix B

Cue words used in Experiment 3 (nouns).

Cue	Spatial association	Visual strength	Cue	Spatial association	Visual strength
ability	0.92	1.23	library	0.23	4.27
advice	1.19	1.12	lobster	−0.76	4.33
agility	0.39	1.58	love	2.03	2.21
anger	−0.40	2.10	mastery	1.08	0.94
ankle	−1.40	3.87	menace	−0.76	1.62
anxiety	−0.24	1.27	mercy	0.72	1.06
arrow	−0.84	4.12	method	0.31	1.00
banner	0.31	4.13	mind	1.11	0.81
barrel	−0.80	3.85	month	0.04	0.94
belief	1.44	0.85	mood	0.48	1.44
bird	0.75	4.40	moral	1.08	0.88
bottle	−0.80	4.13	moss	−1.60	3.94
bowl	−0.84	3.98	mule	−0.72	3.98
brute	−0.60	1.62	oats	−1.16	3.65
bullet	−1.04	3.85	opinion	0.95	0.69
candy	−0.68	3.88	palace	0.92	4.08
cattle	−0.49	4.27	panic	−0.05	2.12
cellar	−1.52	3.88	passion	1.39	1.63
chance	0.43	0.65	pepper	−0.60	3.63
charm	0.72	1.83	piano	−0.29	4.04
coin	−1.16	4.19	pleasure	1.39	1.79
comedy	1.19	2.12	pole	−0.16	3.98
cord	−1.56	3.94	power	1.59	1.52
cost	0.07	1.79	prayer	1.36	1.42
crisis	0.12	1.77	prestige	0.75	1.23
death	−0.60	2.23	pride	1.44	1.44
demon	−1.68	1.94	quest	0.75	1.27
drama	−0.16	1.62	sadness	−0.93	1.60
dream	1.51	2.42	safety	1.63	1.42
duty	0.87	1.04	salad	−0.68	3.90
effort	1.31	1.50	satire	0.00	1.02
ego	0.56	0.77	sauce	−1.08	3.50
flag	0.59	4.27	series	0.12	1.27
flood	−0.93	3.83	shadow	−0.72	3.79
flower	−0.06	4.50	shock	0.28	1.83
forest	0.39	4.33	shoes	−1.32	4.17

(*continued on next page*)

Appendix B (*continued*)

Cue	Spatial association	Visual strength	Cue	Spatial association	Visual strength
fork	−1.12	4.08	skull	−0.57	3.94
fur	−0.60	3.60	sky	2.15	4.33
galaxy	2.31	3.65	slipper	−1.16	4.00
geese	−0.29	4.42	slush	−1.32	2.88
gem	0.12	3.85	snake	−1.37	4.31
glacier	0.20	3.88	spirit	1.47	1.19
gold	0.28	3.87	spree	−0.44	1.29
gravity	−0.21	1.17	star	1.95	4.27
greed	−0.24	1.54	string	−0.80	3.90
green	−0.49	3.87	sugar	−0.44	3.40
grief	−0.65	1.73	sunset	1.44	4.40
hatred	−0.93	1.33	theory	0.56	0.85
heaven	2.39	1.54	ticket	−0.57	4.02
hoof	−1.60	3.46	time	0.67	1.35
hour	0.07	0.79	toast	−0.80	3.77
humor	1.31	1.58	tomb	−1.40	3.75
insect	−1.64	4.27	tool	−0.68	3.81
interest	0.92	1.31	tower	0.22	4.12
irony	−0.05	0.85	toy	−0.60	3.88
jail	−1.76	3.65	tragedy	−0.68	2.17
jelly	−0.88	3.83	tree	0.00	4.44
joy	1.23	2.31	tripod	−0.93	3.92
justice	1.59	1.29	trouble	−0.68	1.37
keg	−0.80	3.88	truck	−0.16	4.38
kettle	−0.60	3.98	trumpet	−0.29	3.63
lawn	−1.04	4.19	truth	1.71	1.17
lecture	−0.13	2.54	vigor	0.48	1.17
lemon	−0.72	3.98	whale	−0.16	4.27

Appendix C

Cue words used in Experiment 4 (verbs).

Cue	Spatial association	Visual strength	Cue	Spatial association	Visual strength
acquire	0.16	1.73	hop	1.15	3.19
adopt	0.08	1.35	hope	1.17	1.17
alarm	0.17	2.25	impact	−0.23	1.90
alienate	−0.35	0.92	increase	1.28	1.67
arise	2.01	1.90	inspire	0.76	1.31
arrive	−0.05	1.88	jog	0.28	3.10
ascend	1.70	2.06	jump	1.28	3.40
block	0.10	3.08	lapse	−1.23	0.67
boost	1.65	1.67	leap	1.46	3.13
bounce	−0.14	2.98	lend	−0.21	1.35
bring	−0.10	1.73	lift	1.30	2.46
carry	0.65	2.40	linger	0.04	1.19
chase	0.21	2.96	lower	−1.19	1.77
clamber	1.22	1.58	march	0.13	3.04
climb	1.69	3.02	perch	0.49	2.50
collect	0.05	1.65	pity	−0.85	1.27

Appendix C (*continued*)

Cue	Spatial association	Visual strength	Cue	Spatial association	Visual strength
commend	0.26	1.19	plummet	−1.97	2.19
confiscate	0.09	1.73	plunge	−1.96	2.48
corrode	−1.17	2.06	prevail	0.70	1.06
cough	−0.06	2.63	provoke	−0.11	1.08
crave	0.36	1.06	punish	−0.98	1.40
crawl	0.05	3.02	push	−0.06	2.58
cross	−0.03	3.38	raise	1.58	1.90
crush	−1.19	2.19	receive	−0.04	1.50
cry	−1.34	2.73	regret	−0.16	0.90
decay	−1.72	2.40	rejoice	1.71	1.75
decline	−1.46	1.38	report	−0.22	2.12
decrease	−1.49	1.29	retrieve	−0.22	1.71
demolish	−1.07	2.81	roam	0.11	2.02
depart	0.08	2.13	rob	−0.18	2.31
depress	−1.11	1.21	roll	−0.34	2.62
descend	−1.54	1.96	run	0.04	2.96
dig	−1.10	2.92	rush	0.02	2.17
dive	−1.93	2.90	sadden	−0.79	1.60
drain	−0.92	2.85	send	−0.01	1.54
dribble	−0.72	2.79	sink	−1.64	3.23
drip	−1.25	2.92	skip	0.69	2.63
drop	−1.70	2.42	slide	−0.25	2.83
elate	0.92	1.44	slump	−1.87	2.42
emerge	1.44	1.94	smash	−0.74	2.77
endure	0.00	1.35	snatch	0.10	2.00
erode	−1.02	2.48	sneeze	0.05	3.00
escalate	1.65	1.42	soar	1.79	2.63
escape	0.23	1.60	spring	1.29	2.85
exist	0.29	1.27	sprout	1.47	2.98
expel	−0.29	1.38	stagger	−0.23	2.83
fail	−1.98	1.21	stop	−0.14	1.75
fall	−2.02	2.85	swap	−0.14	1.81
flee	−0.01	2.44	sweep	−0.24	3.13
float	1.18	2.67	tempt	0.15	1.10
flourish	1.57	1.67	thank	0.06	1.62
flower	0.96	4.50	think	0.57	1.06
fly	1.37	3.21	thrive	1.49	1.15
follow	0.07	2.31	tow	0.12	2.73
frown	−1.03	3.60	tower	1.85	4.12
gallop	0.27	2.94	transfer	−0.09	1.56
glide	0.06	2.44	tremble	−0.38	2.44
grow	1.74	2.42	tumble	−1.84	2.94
guide	0.12	1.88	wade	−0.21	2.58
hang	−0.48	2.63	wait	−0.23	1.19
haul	0.29	2.31	walk	0.01	3.58
heighten	1.15	1.29	wash	−0.62	2.90
hoist	0.90	2.17	wither	−1.35	2.23
hold	0.35	1.88	yank	−0.33	2.25

D. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jml.2015.06.002.

References

Adelman, J. S., Brown, G. D., & Quesada, J. F. (2006). Contextual diversity, not word frequency, determines word-naming and lexical decision times. *Psychological Science, 17*, 814–823.

Altmann, G. T., & Kamide, Y. (2007). The real-time mediation of visual attention by language and world knowledge: Linking anticipatory

(and other) eye movements to linguistic processing. *Journal of Memory and Language, 57*, 502–518.
Amsel, B. D., Urbach, T. P., & Kutas, M. (2012). Perceptual and motor attribute ratings for 559 object concepts. *Behavior Research Methods, 44*, 1028–1041.
Balota, D. A., Yap, M. J., Cortese, M. J., Hutchison, K. A., Kessler, B., Loftis, B., et al. (2007). The English lexicon project. *Behavior Research Methods, 39*, 445–459.
Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68*, 255–278.
Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59*, 617–645.
Barsalou, L. W. (2009). Simulation, situated conceptualization, and prediction. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*, 1281–1289.
Barsalou, L. W., & Wiemer-Hastings, K. (2005). Situating abstract concepts. In D. Pecher & R. A. Zwaan (Eds.), *Grounding cognition: The role of perception and action in memory, language, and thinking* (pp. 129–163). Cambridge, England: Cambridge University Press.
Bergen, B. K., Lindsay, S., Matlock, T., & Narayanan, S. (2007). Spatial and linguistic aspects of visual imagery in sentence comprehension. *Cognitive Science, 31*, 733–764.
Bird, H., Franklin, S., & Howard, D. (2001). Age of acquisition and imageability ratings for a large set of words, including verbs and function words. *Behavior Research Methods, Instruments, and Computers, 33*, 73–79.
Brookshire, G., Ivry, R., & Casasanto, D. (2010). Modulation of motor-meaning congruity effects for valenced words. In *32nd annual meeting of the cognitive science society* (pp. 1940–1945). Cognitive Science Society.
Brysbaert, M., & New, B. (2009). Moving beyond Kučera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Methods, 41*, 977–990.
Chasteen, A. L., Burdzy, D. C., & Pratt, J. (2010). Thinking of God moves attention. *Neuropsychologia, 48*, 627–630.
Clark, J. M., & Paivio, A. (2004). Extensions of the Paivio, Yuille, and Madigan (1968) norms. *Behavior Research Methods, Instruments, and Computers, 36*, 371–383.
Connell, L., & Lynott, D. (2014). I see/hear what you mean: Semantic activation in visual word recognition depends on perceptual attention. *Journal of Experimental Psychology: General, 143*, 527–533.
Connell, L., & Lynott, D. (2010). Look but don't touch: Tactile disadvantage in processing modality-specific words. *Cognition, 115*, 1–9.
Connell, L., & Lynott, D. (2011). Modality switching costs emerge in concept creation as well as retrieval. *Cognitive Science, 35*, 763–778.
Connell, L., & Lynott, D. (2012). Strength of perceptual experience predicts word processing performance better than concreteness or imageability. *Cognition, 125*, 452–465.
Cortese, M. J., & Fugett, A. (2004). Imageability ratings for 3000 monosyllabic words. *Behavior Research Methods, Instruments, and Computers, 36*, 384–387.
Crump, M. J., McDonnell, J. V., & Gureckis, T. M. (2013). Evaluating Amazon's Mechanical Turk as a tool for experimental behavioral research. *PLoS One, 8*, e57410.
Dahan, D., & Tanenhaus, M. K. (2005). Looking at the rope when looking for the snake: Conceptually mediated eye movements during spoken-word recognition. *Psychonomic Bulletin & Review, 12*, 453–459.
Dudschig, C., Lachmair, M., de la Vega, I., De Filippis, M., & Kaup, B. (2012). From top to bottom: Spatial shifts of attention caused by linguistic stimuli. *Cognitive Processes, 13*, S151–S154.
Dudschig, C., Souman, J., Lachmair, M., de la Vega, I., & Kaup, B. (2013). Reading "sun" and looking up: The influence of language on saccadic eye movements in the vertical dimension. *PLoS One, 8*, e56872.
Estes, Z., Verges, M., & Barsalou, L. W. (2008). Head up, foot down: Object words orient attention to the objects' typical location. *Psychological Science, 19*, 93–97.
Field, A. (2009). *Discovering statistics using SPSS* (3rd ed.). London: Sage.
Fischer, M. H., & Zwaan, R. A. (2008). Embodied language: A review of the role of the motor system in language comprehension. *Quarterly Journal of Experimental Psychology, 61*, 825–850.
Friendly, M., Franklin, P. E., Hoffman, D., & Rubin, D. C. (1982). The Toronto Word Pool: Norms for imagery, concreteness, orthographic variables, and grammatical usage for 1080 words. *Behavior Research Methods & Instrumentation, 14*, 375–399.
Gallese, V., & Lakoff, G. (2005). The brain's concepts: The role of the sensory-motor system in conceptual knowledge. *Cognitive Neuropsychology, 22*, 455–479.
Goodhew, S. C., McGaw, B., & Kidd, E. (2014). Why is the sunny side always up? Explaining the spatial mapping of concepts by language use. *Psychonomic Bulletin & Review* (advance online publication).
Gozli, D. G., Chasteen, A. L., & Pratt, J. (2013). The cost and benefit of implicit spatial cues for visual attention. *Journal of Experimental Psychology: General, 142*, 1028–1046.
Hommel, B. (2004). Event files: Feature binding in and across perception and action. *Trends in Cognitive Sciences, 8*, 494–500.
Hommel, B., Pratt, J., Colzato, L., & Godijn, R. (2001). Symbolic control of visual attention. *Psychological Science, 12*, 360–365.
Juhasz, B. J., Yap, M. J., Dicke, J., Taylor, S. C., & Gullick, M. M. (2011). Tangible words are recognized faster: The grounding of meaning in sensory and perceptual systems. *Quarterly Journal of Experimental Psychology, 64*, 1683–1691.
Kaup, B., De Filippis, M., Lachmair, M., de la Vega, I., & Dudschig, C. (2012). When up-words meet down-sentences: Evidence for word- and sentence-based compatibility effects? *Cognitive Processes, 13*, S203–S207.
Klein, R. M. (2000). Inhibition of return. *Trends in Cognitive Sciences, 4*, 138–147.
Kousta, S.-T., Vigliocco, G., Vinson, D. P., Andrews, M., & Del Campo, E. (2011). The representation of abstract words: Why emotion matters. *Journal of Experimental Psychology: General, 140*, 14–34.
Lachmair, M., Dudschig, C., De Filippis, M., de la Vega, I., & Kaup, B. (2011). Root versus roof: Automatic activation of location information during word processing. *Psychonomic Bulletin & Review, 18*, 1180–1188.
Lakens, D. (2012). Polarity correspondence in metaphor congruency effects: Structural overlap predicts categorization times for bipolar concepts presented in vertical space. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 38*, 726–736.
Lakoff, G., & Johnson, M. (1980). The metaphorical structure of the human conceptual system. *Cognitive Science, 4*, 195–208.
Lebois, L. A. M., Wilson-Mendenhall, C. D., & Barsalou, L. W. (2015). Are automatic conceptual cores the gold standard of semantic processing? The context-dependence of spatial meaning in grounded congruency effects. *Cognitive Science* (in press).
Louwerse, M., & Connell, L. (2011). A taste of words: Linguistic context and perceptual simulation predict the modality of words. *Cognitive Science, 35*, 381–398.
Lu, C. H., & Proctor, R. W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin & Review, 2*, 174–207.
Lynott, D., & Connell, L. (2009). Modality exclusivity norms for 423 object properties. *Behavior Research Methods, 41*, 558–564.
Lynott, D., & Connell, L. (2012). Modality exclusivity norms for 400 nouns: The relationship between perceptual experience and surface word form. *Behavior Research Methods, 45*, 1–11.
Lynott, D., & Coventry, K. (2014). On the ups and downs of emotion: Testing between conceptual-metaphor and polarity accounts of emotional valence-spatial location interactions. *Psychonomic Bulletin & Review, 21*, 218–226.
Martin, A. (2007). The representation of object concepts in the brain. *Annual Review of Psychology, 58*, 25–45.
Meier, B. P., Hauser, D. J., Robinson, M. D., Friesen, C. K., & Schjeldahl, K. (2007). What's "up" with God? Vertical space as a representation of the divine. *Journal of Personality and Social Psychology, 93*, 699–710.
Meteyard, L., Bahrami, B., & Vigliocco, G. (2007). Motion detection and motion verbs: Language affects low-level visual perception. *Psychological Science, 18*, 1007–1013.
Meteyard, L., & Vigliocco, G. (2009). Verbs in space: Axis and direction of motion norms for 299 English verbs. *Behavior Research Methods, 41*, 565–574.
Miller, G. A., & Johnson-Laird, P. N. (1976). *Language and perception*. Cambridge: Belknap Press.
Mills, M., Smith, K. B., Hibbing, J. R., & Dodd, M. D. (2015). Obama cares about visuo-spatial attention: Perception of political figures moves attention and determines gaze direction. *Behavioural Brain Research, 278*, 221–225.
Ouellet, M., Santiago, J., Funes, M. J., & Lupianez, J. (2010). Thinking about the future moves attention to the right. *Journal of Experimental Psychology: Human Perception and Performance, 36*, 17–24.
Paivio, A., Yuille, J. C., & Madigan, S. A. (1968). Concreteness, imagery, and meaningfulness values for 925 nouns. *Journal of Experimental Psychology, 76*, 1–25.
Paolacci, G., & Chandler, J. (2014). Inside the Turk: Understanding Mechanical Turk as a participant pool. *Current Directions in Psychological Science, 23*, 184–188.
Pecher, D., Boot, I., & van Dantzig, S. (2011). Abstract concepts: Sensory-motor grounding, metaphors, and beyond. In B. H. Ross (Ed.).

Psychology of learning and motivation (Vol. 54, pp. 217–248). Burlington: Academic Press.
Pecher, D., van Dantzig, S., & Schifferstein, H. N. J. (2009). Concepts are not represented by conscious imagery. *Psychonomic Bulletin & Review, 16*, 914–919.
Pecher, D., & Zwaan, R. A. (2005). *Grounding cognition: The role of perception and action in memory, language, and thinking*. Cambridge, England: Cambridge University Press.
Proctor, R. W., & Cho, Y. S. (2006). Polarity correspondence: A general principle for performance of speeded binary classification tasks. *Psychological Bulletin, 132*, 416–442.
Pulvermuller, F., & Fadiga, L. (2010). Active perception: Sensorimotor circuits as a cortical basis for language. *Nature Reviews Neuroscience, 11*, 351–360.
Quadflieg, S., Etzel, J. A., Gazzola, V., Keysers, C., Schubert, T. W., Waiter, G. D., et al. (2011). Puddles, parties, and professors: Linking word categorization to neural patterns of visuospatial coding. *Journal of Cognitive Neuroscience, 23*, 2636–2649.
Reilly, J., & Kean, J. (2007). Formal distinctiveness of high- and low-imageability nouns: Analyses and theoretical implications. *Cognitive Science, 31*, 157–168.
Reimers, S., & Stewart, N. (2015). Presentation and response timing accuracy in Adobe Flash and HTML5/JavaScript Web experiments. *Behavior Research Methods, 47*, 309–327.
Richardson, D. C., & Spivey, M. J. (2000). Representation, space and Hollywood Squares: Looking at things that aren't there anymore. *Cognition, 76*, 269–295.
Richardson, D. C., Spivey, M. J., Barsalou, L. W., & McRae, K. (2003). Spatial representations activated during real-time comprehension of verbs. *Cognitive Science, 27*, 767–780.
Santiago, J., & Lakens, D. (2015). Can conceptual congruency effects between number, time, and space be accounted for by polarity correspondence? *Acta Psychologica, 156*, 179–191.
Schock, J., Cortese, M. J., & Khanna, M. M. (2012). Imageability estimates for 3000 disyllabic words. *Behavior Research Methods, 44*, 374–379.
Schubert, T. W. (2005). Your highness: Vertical positions as perceptual symbols of power. *Journal of Personality and Social Psychology, 89*, 1–21.
Šetić, M., & Domijan, D. (2007). The influence of vertical spatial orientation on property verification. *Language and Cognitive Processes, 22*, 297–312.
Spivey, M. J., & Geng, J. J. (2001). Oculomotor mechanisms activated by imagery and memory: Eye movements to absent objects. *Psychological Research, 65*, 235–241.
Spivey, M. J., Tyler, M. J., Eberhard, K. M., & Tanenhaus, M. K. (2001). Linguistically mediated visual search. *Psychological Science, 12*, 282–286.
Thornton, T., Loetscher, T., Yates, M. J., & Nicholls, M. E. R. (2013). The highs and lows of the interaction between word meaning and space. *Journal of Experimental Psychology: Human Perception and Performance, 39*, 964–973.
Toglia, M. P., & Battig, W. F. (1978). *Handbook of semantic word norms*. Oxford, England: Lawrence Erlbaum.
Ungerleider, L. G., & Haxby, J. V. (1994). 'What' and 'where' in the human brain. *Current Opinion in Neurobiology, 4*, 157–165.
van Dantzig, S., Cowell, R. A., Zeelenberg, R., & Pecher, D. (2011). A sharp image or a sharp knife: Norms for the modality-exclusivity of 774 concept-property items. *Behavior Research Methods, 43*, 145–154.
van Dantzig, S., Pecher, D., Zeelenberg, R., & Barsalou, L. W. (2008). Perceptual processing affects conceptual processing. *Cognitive Science, 32*, 579–590.
Verges, M., & Duffy, S. (2009). Spatial representations elicit dual-coding effects in mental imagery. *Cognitive Science, 33*, 1157–1172.
Wiemer-Hastings, K., & Xu, X. (2005). Content differences for abstract and concrete concepts. *Cognitive Science, 29*, 719–736.
Zacks, J. M., Speer, N. K., Swallow, K. M., Braver, T. S., & Reynolds, J. R. (2007). Event perception: A mind-brain perspective. *Psychological Bulletin, 133*, 273–293.
Zhang, E., Luo, J., Zhang, J., Wang, Y., Zhong, J., & Li, Q. (2013). Neural mechanisms of shifts of spatial attention induced by object words with spatial associations: An ERP study. *Experimental Brain Research, 227*, 199–209.
Zwaan, R. A., & Taylor, L. J. (2006). Seeing, acting, understanding: Motor resonance in language comprehension. *Journal of Experimental Psychology: General, 135*, 1–11.
Zwaan, R. A., & Yaxley, R. H. (2003). Spatial iconicity affects semantic relatedness judgments. *Psychonomic Bulletin & Review, 10*, 954–958.