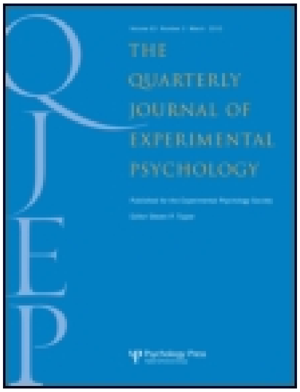


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# Perceptual simulations and linguistic representations have differential effects on speeded relatedness judgements and recognition memory

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# Perceptual simulations and linguistic representations have differential effects on speeded relatedness judgements and recognition memory

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We examined the effect of spatial iconicity (a perceptual simulation of canonical locations of objects) and word-order frequency on language processing and episodic memory of orientation. Participants made speeded relatedness judgements to pairs of words presented in locations typical of their real-world arrangements (e.g., *ceiling* on top and *floor* on bottom). They then engaged in a surprise orientation recognition task for the word pairs. We replicated Louwerse's (2008) finding that word-order frequency has a stronger effect on semantic relatedness judgements than does spatial iconicity. This is consistent with recent suggestions that linguistic representations have a stronger impact on immediate decisions about verbal materials than do perceptual simulations. In contrast, spatial iconicity enhanced episodic memory of orientation to a greater extent than word-order frequency did. This new finding indicates that perceptual simulations have an important role in episodic memory. Results are discussed with respect to theories of perceptual representation and linguistic processing.

*Keywords*: Embodied cognition; Language processing; Orientation recognition; Spatial iconicity; Word-order frequency.

Recent theories of knowledge representation argue that the perceptual systems serve to represent knowledge via a simulation process that produces an internally generated percept of a word's referent (Barsalou, 2008; Zwaan, 2004). This view has been supported by a number of sentence-processing studies, which demonstrated that readers generate modality-specific perceptual simulations of events during language comprehension (see Barsalou, 2008, for a review). For example, Stanfield and Zwaan (2001) reported that participants recognized a picture of an object in a particular orientation (*a pen in vertical position*) more quickly immediately after reading a sentence that implied

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a matching orientation for that pictured object (*John put the pencil in the cup*). Evidence suggests that readers also generate motor simulations of described actions. Glenberg and Kaschak (2002, see also Zwaan & Taylor, 2006) found that participants were faster to judge the sensibility of a sentence (*You handed Courtney the notebook*) when the arm movement required to make the judgement was compatible with the action described by the sentence (*away from the body*) than when it was incompatible (*toward the body*). Pecher, Zeelenberg, and Barsalou (2003, 2004) showed that perceptual simulations participate in conceptual judgements about objects. Even though in their task only visually presented verbal stimuli were used, they found that a perceptual simulation associated with multiple modalities might still occur. For example, participants verified a property related to the olfactory modality (*soap–perfumed*) more quickly after verifying a property related to the same modality (*old book–musty*) than after verifying a property related to a different modality (*television–noisy*).

The above studies demonstrate that perceptual representations participate in immediate, speeded judgements. However, little evidence speaks to whether or not perceptual simulations have long-lasting effects on memory (see Pecher, van Dantzig, Zwaan, & Zeelenberg, 2009; Pecher, Zanolie, & Zeelenberg, 2007; for some recent examples). Such effects would help elucidate the roles that perceptual simulations may play in cognition. Some researchers (e.g., Louwerse, 2008; Louwerse & Jeuniaux, 2008) have recently argued that linguistic properties of word stimuli reflect embodied relations in the world, which may partially account for the above embodiment effects in language-processing tasks. Hence, it is difficult to ascertain to what extent perceptual simulations influence cognition beyond the immediate, and to what extent perceptual simulations and linguistic representations contribute uniquely to embodiment effects. In the present research, we investigated how one form of perceptual simulation—spatial iconicity—could affect immediate relatedness judgements and subsequent memory for words and whether linguistic properties of the word stimuli could at least partially account for performance in these two cognitive tasks.

As coined by Zwaan and Yaxley (2003), the spatial iconicity effect refers to the finding that readers tend to use simulations about the typical, or *iconic*, spatial locations of words to facilitate judgements of semantic relatedness. In their Experiment 1, participants made speeded semantic relatedness judgements of pairs of words, such as *car–road*, that were arranged in a spatially iconic orientation, with *car* on the top of the computer screen and *road* on the bottom, or noniconic orientation, with *car* on the bottom and *road* on top. Relatedness judgements were faster when the words were presented in an iconic orientation than in a noniconic orientation, which Zwaan and Yaxley interpreted as evidence that participants generated perceptual simulations of the typical spatial locations of the words. This finding has been obtained in other tasks. Setic and Domijan (2007) found that participants' living–nonliving judgements were faster when the location of an object word on the screen was consistent with the typical location of its referent in the world (*eagle* on top) than when it was not (*eagle* on bottom). Estes, Verges, and Barsalou (2008) found that an object word (*eagle*) presented at the centre of the screen would interfere with discrimination of an unrelated visual target (*X* or *O*) subsequently presented in the typical, iconic location of that word (i.e., on the top). These authors reasoned that the object word reflexively oriented participants' attention toward the object's typical location and activated a perceptual simulation of the denoted object. Because the simulated object (an eagle) and the subsequent perceptual target (*X*) shared few features, participants needed to inhibit the activated yet irrelevant perceptual simulation so as to identify the target. This shows that spatial iconicity of object words has an effect not only on language processing, but also on how attention is oriented. Given that previous studies showed that memory encoding can be facilitated under focused attention (e.g., Naveh-Benjamin, Craik, Guez, & Dori, 1998), the object words presented in the typical location may be encoded more deeply and in turn be better remembered.

However, whether perceptual simulation is the only account for the spatial iconicity effect is debatable. According to Louwerse (2008, see also Louwerse & Jeuniaux, 2008), linguistic representations tend to code information that is extracted from our perceptual experiences. The fact that people respond faster when the word *car* is presented at the top of the screen and *road* on the bottom, rather than the other way around, might reflect that *car* precedes *road* more frequently in everyday language use. This account is complementary to the embodied account because it does not deny the occurrence of perceptual simulation, but suggests that performance in speeded tasks may be equally, or better, predicted by linguistic representations. Indeed, Louwerse suggests that prelinguistic, perceptual simulations of real-world experiences (e.g., a *car* being often at the top of a *road*) shape our linguistic representations (e.g., word-order frequency of *car*–*road*). Because people develop language through their interaction with the real world, embodied relations are encoded in language (Louwerse, 2008). He reanalysed Zwaan and Yaxley's (2003) word stimuli and found that word-order frequency is correlated with spatial iconicity. In his replication study (of Zwaan & Yaxley, 2003), regression analyses showed that word-order frequency predicted the "spatial iconicity" effect better than spatial iconicity itself did in relatedness judgements. Louwerse and Zwaan (2009) further showed that geographically accurate locations of cities can be extracted from word co-occurrences based on text corpora. In the present study we used Zwaan and Yaxley's paradigm and adapted Louwerse's analytic strategies in order to replicate their relatedness judgement findings, which is one goal of our study.

Apart from immediate judgements, perceptual simulation has also been shown to have a subsequent effect on episodic memory performance. Pecher et al. (2007) found that in a delayed picture recognition memory task, participants showed superior memory for the picture of an object (*apple*) after its name had been presented with a visual property (*apple*–*shiny*) than after it had been presented with a nonvisual property (*apple*–*tart*) in a property verification task. These authors argued that because a modality-specific simulation (visual experience of a shiny apple) occurred when participants verified the property of an apple, their memory was effectively cued when they were tested with a picture that visually depicted an apple. Indeed, when the word (*apple*), instead of the picture, was used as the test item, the difference in recognition memory for the object names verified with visual versus nonvisual properties was eliminated. Using a modified Stanfield and Zwaan (2001) paradigm, Pecher et al. (2009) separated the sentence comprehension and picture recognition phases. They found that memory was better when the orientation/shape of the objects of the pictures matched the orientation/shape of the objects implied by the sentence in the study phase. This effect occurred regardless of whether the memory task was given immediately or after a 45-minute filled delay. In our present study, we added a surprise recognition memory test at the end of the Zwaan and Yaxley (2003) paradigm in order to examine whether pairs presented in an iconic orientation in the prior relatedness judgement task could facilitate subsequent memory performance better than those presented in a noniconic orientation, which is another goal of our study.

To summarize, in the present study we investigated whether one type of perceptual simulation—spatial iconicity of two words at study—would affect immediate relatedness judgements and subsequent recognition memory for the orientation in which they had been presented. Further, we assessed to what extent word order explained these effects in order to understand the role of linguistic representations in the spatial iconicity effects, consistent with Louwerse (2008). At study, we adapted Zwaan and Yaxley's (2003) procedure: Participants judged the semantic relatedness of two words, which were presented in either an iconic (*car* at the top of the screen and *road* at the bottom) or a noniconic orientation (*car* at the bottom and *road* at the top). Immediately after completing all trials in the relatedness judgement task, participants were given a surprise orientation recognition task, in which they were presented the same set of word pairs that they had judged at study. Half of these pairs appeared in the same orientation, whereas the other half appeared in reversed orientation. The participants decided whether the test pairs were presented in the same orientation as that in the relatedness judgement task. For the relatedness judgement task, we expected to replicate Zwaan and Yaxley's findings of faster relatedness judgements for pairs in the iconic condition than for those in the noniconic condition. We used Louwerse's regression procedure to test whether word-order frequency would predict relatedness judgement performance better than spatial iconicity. For the orientation recognition task, we expected participants to show better memory for pairs that had been presented in their iconic orientation than for those that had been presented in a noniconic orientation. We then performed regression analyses, adapting procedures from Louwerse (2008), on these data to explore whether spatial iconicity or word-order frequency is a better predictor for performance in the orientation recognition task.

## Method

### *Participants*

A total of 60 undergraduates with normal or corrected-to-normal vision participated for course credit. Data from 4 additional participants were replaced due to their unusually high error rates in the relatedness judgement task (>15%).

### *Design and materials*

In the relatedness judgement task, we used a within-subject design with iconicity (iconic vs. noniconic) as the repeated measure. In the orientation recognition task, we used a 2 (iconicity: iconic vs. noniconic) × 2 (type of test pairs: intact vs. rearranged) within-subject design.

The 32 critical word pairs were chosen from Zwaan and Yaxley (2003). They are names of common objects or parts of objects that are canonically viewed in a fixed vertical relation—for example, an *airplane* is typically above a *runway*, and an *attic* is above a *basement* in the canonical view of a house. For counterbalancing purposes, the word pairs were divided into two groups of 16. In the relatedness judgement task, half of the participants saw one group of word pairs matched to the canonical vertical orientation of their referents (i.e., iconic) and the other mismatched (i.e., noniconic), and the remaining half of participants saw the reversed assignment. Because all of the critical pairs were semantically related, a set of 32 semantically related and 32 semantically unrelated filler pairs were included. We included the two different types of filler pairs in order to replicate, as closely as possible, the procedure used by Zwaan and Yaxley (2003).

The mean lexical characteristics of all these pairs are summarized in Table 1. The full set of materials is presented in the Appendix. The filler pairs were matched to the critical pairs on word

**Table 1.** *Means and standard deviations of lexical characteristics of stimuli*

| | | *Filler pairs* | |
|---|---|---|---|
| | *Critical word pairs* | *Semantically related* | *Semantically unrelated* |
| Word length (in no. of characters) | $5.27^{a}$ (1.55) | $5.42^{a}$ (1.02) | $5.31^{a}$ (0.83) |
| Log HAL word frequency | $8.95^{a}$ (1.60) | $9.14^{a}$ (1.68) | $9.26^{a}$ (1.38) |
| Lexical decision RT (in ms) | $617^{a}$ (56) | $610^{a}$ (47) | $614^{a}$ (48) |
| Lexical decision accuracy | $.97^{a}$ (.04) | $.97^{a}$ (.03) | $.98^{a}$ (.03) |
| Forward associative strength | $.12^{a}$ (.18) | $.12^{a}$ (.08) | $.00^{b}$ (—) |
| Backward associative strength | $.07^{a}$ (.13) | $.09^{a}$ (.05) | $.00^{b}$ (—) |
| LSA cosines | $.40^{a}$ (.21) | $.40^{a}$ (.20) | $.04^{b}$ (.05) |

*Note:* HAL = Hyperspace Analogue to Language; LSA = Latent Semantic Analysis. The values within each row with different superscripts are significantly different from each other ($p < .05$, two-tailed). Standard deviations in parentheses.

length, log HAL (Hyperspace Analogue to Language) word frequency, and lexical decision reaction time and accuracy (Balota et al., 2007). We matched the words on lexical decision performance in order to make sure they were equally familiar to the participants. The semantically related pairs were also matched to the critical pairs on forward and backward associative strength (Nelson, McEvoy, & Schreiber, 2004) and Latent Semantic Analysis (LSA) cosines (Landauer & Dumais, 1997) to equate their degrees of semantic relatedness. To obtain LSA cosines for each word pair, we applied the pairwise comparison function, general-reading-up-to-1st-year-in-college-database, and the maximum number of factors in http://lsa.colorado.edu (Landauer & Dumais, 1997). Unlike the critical word pairs, none of the filler pairs had a clear vertical spatial relationship. As in Zwaan and Yaxley (2003; see their Footnote 1), forward associative strength and backward associative strength were not significantly different for critical word pairs (.12 vs. .07), $t(31) = 1.31$, $p = .20$, $d = 0.33$, and semantically related filler pairs (.12 vs. .09), $t(31) = 1.57$, $p = .13$, $d = 0.40$. We obtained word-order frequencies from Louwerse (2008), which were calculated based on three to five word grams in the Web 1T 5-gram corpus (Brants & Franz, 2006; and see Louwerse, 2008, for additional details).

In the surprise orientation recognition task, all 32 critical word pairs were presented again. However, half of the pairs in the iconic and non-iconic conditions were presented in the same, intact orientation, whereas the other half were presented in a rearranged orientation with the top and bottom word locations reversed. Thus, 8 critical word pairs were assigned to each of 2 (iconicity: iconic vs. noniconic) × 2 (type of test pair: intact vs. rearranged) cells in the orientation recognition task, with this assignment counterbalanced across participants.[1]

### *Procedure*

All words were presented on a computer screen in white font (size 18) against a black background. In the relatedness judgement task, each trial began with a 1,000-ms fixation point at the centre of the screen. Following the offset of the fixation point, a word pair was displayed for 5 seconds. The two words subtended 1.35° of vertical visual angle at a viewing distance of 55 cm. The participants were instructed to judge whether they were related or unrelated in meaning by pressing the *L* key (labelled *Y* for "yes") using their right index finger for related pairs or the *A* key (labelled *N* for "no") using their left index finger for unrelated pairs. They were encouraged to respond as quickly and as accurately as possible and make their decision based on their first impression. Participants were notified that the word pair would stay on the screen for 5 seconds regardless of their speed or accuracy. The first four and last four trials were practice trials and recency buffer trials, respectively, which consisted of filler pairs, with half related and half unrelated.

Immediately after completing the relatedness judgement task for all of the word pairs, participants were given a surprise orientation recognition task. That is, they did not expect to receive a memory task when they were doing the relatedness judgement task. In this task, each trial began with a 1,000-ms fixation point at the centre of the screen. Following the offset of the fixation point, a word pair was displayed on the screen until the participant responded. The participants were instructed to judge whether each test pair was presented in the same or different orientation as in the relatedness judgement task by pressing the *L* key (labelled *Y*) using their right index finger for intact pairs or the *A* key (labelled *N*) using their left index finger for rearranged pairs. Participants were given examples in the task instructions, and the experimenters made sure that they understood the task requirements. They were also encouraged

[1] One could argue that the semantically related and unrelated filler pairs could be included in the orientation recognition test as a baseline condition. However, because two different sets of stimuli were used for the iconic pairs and the filler pairs, even though we tried to match as many lexical variables as possible for them, there could be some unknown lexical characteristics that have not been equated (e.g., word-order frequency). This would cloud the interpretation of their orientation recognition (as well as relatedness judgement) performance, had they been used as the baseline condition.

**Table 2.** *Performance in relatedness judgement and orientation recognition tasks*

| | | *Critical word pairs* | | *Filler pairs* | |
|---|---|---|---|---|---|
| | | *Iconic* | *Noniconic* | *Related* | *Unrelated* |
| Relatedness judgement | Mean RTs (in ms) | 1,486[a] (344) | 1,523[b] (365) | 1,444[c] (320) | 1,623[d] (406) |
| | Mean errors (in %) | 5.52[a] (7.81) | 5.52[a] (6.82) | 1.91[b] (2.59) | 4.52[a] (5.84) |
| Orientation recognition | Mean hit rate | .78[a] (.20) | .70[b] (.21) | — | — |
| | Mean false-alarm rate | .42[a] (.17) | .50[b] (.19) | — | — |
| | Median hit RTs (in ms) | 1,493[a] (466) | 1,722[b] (806) | — | — |
| | Median correct rejection RTs (in ms) | 1,754[a] (474) | 1,781[a] (650) | — | — |
| | Mean $d'$ | 1.28[a] (1.05) | 0.68[b] (1.05) | — | — |
| | Mean $C$ | −.37[a] (.51) | −.32[a] (.50) | — | — |

*Note:* A hit response refers to an intact response to a test pair that is in the same orientation as that presented in the relatedness judgement task. A false-alarm response refers to an intact response to a test pair that is in a rearranged orientation as presented in the relatedness judgement task. The values within each row with different superscripts are significantly different from each other ($p < .05$, two-tailed). Standard deviations in parentheses.



to respond as quickly and as accurately as possible. The first four trials were practice trials, which consisted of two intact and two rearranged filler pairs that were presented in the relatedness judgement task. These practice trials were included to familiarize the participants with the key assignments and task requirements. In both relatedness judgement and orientation recognition tasks, no feedback was given, and the next trial began immediately after the offset of the word pair. The reaction time (RT) in milliseconds (ms) and accuracy to each word pair were recorded. The whole experiment took approximately 15–20 min.

## Results

For the relatedness judgement task, errors and correct responses faster than 200 ms were first removed. About 1.5% of correct responses were then eliminated due to their RTs being 3 standard deviations above or below the participant's overall mean. In the orientation recognition task, in addition to the hit and false-alarm measures, participants' memory performance was also assessed by two signal detection measures, $d'$ (memory discrimination) and $C$ (criterion placement). The proportions of 1 and 0 were converted to .99 and .01, respectively, for computing $d'$ and $C$. The following analyses for critical word pairs were conducted with participants ($F_1$ and $t_1$) or items ($F_2$ and $t_2$) as the random factor. Partial eta-squared (i.e., $\eta_p^2$) and Cohen's $d$ (i.e., $d$) are effect sizes of $F$ and $t$ statistics for analysis of variance (ANOVA), respectively.

### *Relatedness judgements*

Table 2 presents the RTs and error rates for each condition. Participants responded faster to pairs in the iconic orientation than to those in the noniconic orientation, $t_1(59) = 2.34$, $p < .05$, $d = 0.43$; $t_2(31) = 2.07$, $p < .05$, $d = 0.52$. Their RTs were faster for related filler pairs than for all other types of pairs and slower for unrelated filler pairs than for all other types of pairs (all $t$s $> 2.46$, $p$s $< .05$, $d$s $> 0.45$). For errors, participants were as accurate for pairs in the iconic condition as for those in the noniconic condition, $t_1(59) = 0.00$, $d = 0.00$; $t_2(31) = 0.00$, $d = 0.00$. While the errors for related semantically related filler pairs were lower than those for all other types of pairs (all $t$s $> 3.23$, $p$s $< .01$, $d$s $> 0.59$), the errors for unrelated filler pairs were not different from the pairs in the iconic or noniconic conditions (all $t$s $< 1$, $d < 0.15$).

### *Orientation recognition*

Table 2 presents the mean recognition performance for each condition. The pairs in the iconic condition yielded higher hit rates, $t_1(59) = 2.40$,

$p < .05$, $d = 0.44$; $t_2(31) = 2.14$, $p < .05$, $d = 0.54$, lower false-alarm rates, $t_1(59) = 2.83$, $p < .01$, $d = 0.52$; $t_2(31) = 1.98$, $p = .057$, $d = 0.50$, and higher $d'$s, $t_1(59) = 3.89$, $p < .01$, $d = 0.71$; $t_2(31) = 2.11$, $p < .05$, $d = 0.53$, than did the pairs in the noniconic condition. As indicated by *C*, participants did not have different criterion placements for pairs in the iconic versus noniconic conditions, $t_1(59) = 0.71$, $p = .48$, $d = 0.13$; $t_2(31) = 0.02$, $p = .98$, $d = 0.00$. When the difference in false alarms for pairs in the iconic versus noniconic conditions was partialled out (i.e., treated as a covariate), participants' hit rates were still significantly higher for pairs in the iconic condition than for those in the noniconic condition in participant analyses, $F_1(1, 58) = 5.23$, $MSE = 0.03$, $p < .05$, $\eta_p^2 = 0.08$, but not in item analyses, $F_2(1, 30) = 1.90$, $MSE = 0.02$, $p = .18$, $\eta_p^2 = 0.06$. For RTs, participants produced faster hit responses for pairs in the iconic condition than for those in the noniconic condition, although the difference was only significant in the participant analyses, $t_1(59) = 2.65$, $p < .05$, $d = 0.48$; $t_2(31) = 1.23$, $p = .23$, $d = 0.31$. There was no difference in correct rejection RTs for pairs in the iconic versus the noniconic conditions, $t_1(59) = 0.42$, $p = .68$, $d = 0.08$; $t_2(31) = 1.04$, $p = .31$, $d = 0.26$. All of the orientation recognition findings remained qualitatively the same when the analyses were restricted only to the pairs that had been correctly judged in the preceding relatedness judgement task.

### *Regression analyses*

We tested the effects of spatial iconicity and word-order frequency on relatedness judgement and orientation recognition performance. Because participants' relatedness judgements and recognition decisions should be considered at the person level, and not treated as independent observations, we performed regressions across participants, after controlling for overall individual differences in performance, and within-participant regressions, following the procedures detailed in Louwerse (2008). We only performed analyses on the dependent variables that yielded significant effects of spatial iconicity in the ANOVAs, except $d'$ because it was based on participants' *aggregated* hit and false-alarm rates. In the first *residual* analyses, we entered all 60 dummy-coded participants into linear regression models in a stepwise fashion separately for relatedness judgement RTs and hit RTs, and into logistic regression models in a stepwise fashion separately for hit and false-alarm rates. Residuals of these analyses were saved and used as dependent variables for subsequent regression analyses with a categorical spatial iconicity variable (0 = noniconic vs. 1 = iconic) and a continuous word-order frequency variable as predictors. Due to the low correlation between spatial iconicity and word-order frequency ($r = .11$, $p < .01$), both variables were entered simultaneously in the regression model.[2] In the second *participant* analyses (see Lorch & Myers, 1990, for more details), we created a regression model for each participant, using spatial iconicity and word-order frequency as the predictors separately on relatedness judgement RTs and hit RTs, and then performed paired-sample *t* tests on the beta weights of these two variables obtained from the participant analyses for comparing the effects of spatial iconicity and word-order frequency. Finally, unlike Louwerse (2008), we also performed regression analyses on the data at the item level, with spatial iconicity and word-order frequency as the predictors, in order to yield converging support for the above analyses. The item analyses also allowed us to examine how $d'$ was modulated by spatial iconicity and word-order frequency. We performed all of the above regression analyses

[2] We treated spatial iconicity as a categorical variable and word-order frequency as a continuous variable because (a) the range of the spatial iconicity ratings, based on the Louwerse's (2008) norms, is highly restricted in the stimuli we adapted from Zwaan and Yaxley (2003; 4.04–5.61 in a 6-point scale), so this may mask the effect of spatial iconicity in the regression analyses, (b) the range of word-order frequency is large (0–169,711), so dichotomizing this variable may reduce statistical power and sensitivity in the regression analyses, and (c) the correlation between categorical spatial iconicity and categorical word-order frequency was quite high ($r = +.47$), thereby increasing the potential for a multicollinearity problem in the regression analyses.

separately with raw word-order frequency and with log-transformed word-order frequency (to correct for positive skew) and yielded qualitatively identical findings. Thus, in the following section we only report the analyses using raw word-order frequency in order to make them comparable with those reported in Louwerse (2008).

*Relatedness judgements*. In the residual analyses, the regression model based on the 60 dummy-coded participants was significant, $F(59, 4904) = 39.40$, $MSE = 183{,}695$, $p < .01$, $R^2 = .32$. The subsequent regression model on the saved residuals was also significant, $F(2, 1778) = 8.42$, $MSE = 200{,}028$, $p < .01$, $R^2 = .01$. The beta weight was significant for word-order frequency, $\beta = -.09$, $t(778) = -3.58$, $p < .01$, $d = .12$, but not for spatial iconicity, $\beta = -.04$, $t(778) = -1.60$, $p = .11$, $d = .05$. In the participant analysis, the mean beta weight for word-order frequency was also significant, $M = -.125$, $t(59) = 4.99$, $p < .01$, $d = 0.92$, but not for spatial iconicity, $M = -.004$, $t(59) = 0.20$, $p = .84$, $d = 0.04$. The mean beta weight for word-order frequency was also significantly larger in absolute magnitude than that for spatial iconicity, $t(59) = 3.27$, $p < .01$, $d = 0.60$. Finally, in the item analyses, we found that word-order frequency, $t(61) = 1.75$, $p = .09$, $d = 0.32$, rather than spatial iconicity, $t(61) = 0.99$, $p = .33$, $d = 0.18$, predicted relatedness judgement RTs. Hence, all of these regressions converge to provide evidence that is congruent with Louwerse's findings: Relatedness judgement RTs were better explained by word-order frequency than by spatial iconicity.

*Orientation recognition*. In the residual analyses, the regression model based on the 60 dummy-coded participants was significant for hit rates, $\chi^2(59) = 138.70$, $p < .01$, Nagelkerke $R^2 = .20$, false-alarm rates, $\chi^2(59) = 83.09$, $p < .05$, Nagelkerke $R^2 = .11$, and hit RTs, $F(59, 649) = 5.03$, $MSE = 708{,}403$, $p < .01$, $R^2 = .31$. The subsequent regression model on the saved residuals was significant for hit rates, $F(2, 957) = 4.64$, $MSE = 0.17$, $p < .01$, $R^2 = .01$, false-alarm rates, $F(2, 957) = 4.42$, $MSE = 0.23$, $p < .05$, $R^2 = .01$, and hit RTs, $F(2, 706) = 3.68$, $MSE = 644{,}490$, $p < .05$, $R^2 = .01$. We obtained significant beta weights in all three dependent measures (hits, false alarms, and hit RTs) for spatial iconicity—hit rates, $\beta = .09$; $t(957) = 2.83$, $p < .01$, $d = 0.13$; false-alarm rates, $\beta = -.09$; $t(957) = -2.79$, $p < .01$, $d = 0.13$; and hit RTs, $\beta = -.10$; $t(706) = -2.62$, $p < .01$, $d = 0.14$—but not for word-order frequency—hit rates, $\beta = .03$; $t(957) = 0.84$, $p = .40$, $d = 0.04$; false-alarm rates, $\beta = .04$; $t(957) = 1.37$, $p = .17$, $d = 0.06$; and hit RTs, $\beta = .04$; $t(706) = 0.96$, $p = .34$, $d = 0.05$—a pattern exactly opposite to what we found in relatedness judgement data. In the participant analysis on hit RTs,[3] the mean beta weight for spatial iconicity was significant, $M = -.09$, $t(59) = -2.28$, $p < .05$, $d = 0.42$, and marginally greater than that for word-order frequency, $t(59) = -1.93$, $p = .06$, $d = 0.36$, which was itself not significant, $M = .02$, $t(59) = 0.62$, $p = .54$, $d = 0.11$. Finally, in the item analyses, we found that spatial iconicity significantly predicted hit rates, $t(61) = 2.28$, $p < .05$, $d = 0.41$; false-alarm rates, $t(61) = -2.03$, $p < .05$, $d = 0.37$; signal detection measure, $d'$, $t(61) = 2.41$, $p < .05$, $d = 0.44$; and hit RTs, $t(61) = -1.83$, $p = .07$, $d = 0.33$, but word-order frequency did not predict any of these measures: hit rates, $t(61) = 0.07$, $p = .94$, $d = 0.01$; false-alarm rates, $t(61) = 1.05$, $p = .30$, $d = 0.19$; signal detection measure, $d'$, $t(61) = 0.75$, $p = .46$, $d = 0.14$; and hit RTs, $t(61) = 1.45$, $p = .15$, $d = 0.26$. Thus, unlike the relatedness judgement RT analyses, orientation recognition was better explained by spatial iconicity than by word-order frequency.

## Discussion

The findings of the present study are threefold. First, we replicated Zwaan and Yaxley's (2003)

[3] We encountered difficulties performing participant analyses on our hit and false-alarm rates due to extreme observations for some participants (i.e., imbalanced proportion of hits/false alarms and miss/correct rejections). The frequency counts were too low in each cell to conduct interpretable within-subject logistic regression analyses, so we only examined hit RTs with this procedure.

finding that participants made faster relatedness judgements to pairs presented in an iconic orientation (*car* on the top of the screen and *road* on the bottom) than to pairs presented in a noniconic orientation (*car* on the bottom and *road* on top). Second, the pairs presented in an iconic orientation yielded better orientation recognition than those presented in a noniconic orientation in a surprise memory task given immediately after the relatedness judgement task. This effect may not be entirely attributed to response bias because the criterion placement, as measured by *C*, was virtually identical in both iconic and noniconic conditions, and after taking into account the difference in false-alarm rates for pairs in iconic versus noniconic conditions, the hit rates were still significantly higher for pairs in the iconic condition than for those in the noniconic condition. As in previous studies (e.g., Pecher et al., 2009), the use of an incidental learning procedure in our study, and the fact that the memory test was a surprise, rules out the possibility that participants might have used different strategies to encode the pairs in the iconic and noniconic conditions. Third, regression analyses revealed that the facilitation of relatedness judgement RTs could be attributed to word-order frequency being higher when pairs were presented in an iconic orientation (e.g., car–road) than in a noniconic orientation (e.g., road–car), rather than to spatial iconicity. On the contrary, the facilitation in orientation recognition was probably attributed to pairs that had been presented in an iconic orientation (relative to those presented in a noniconic orientation), rather than to differences in word-order frequency. To our knowledge, this is the first study that reveals the dissociative effect of word-order frequency and spatial iconicity on immediate semantic relatedness judgements and subsequent orientation recognition.

Before considering the theoretical implications of the present findings, it is necessary to rule out an alternative explanation for our findings. One could attribute the better orientation recognition for pairs that were presented in an iconic orientation to proactive interference from participants' knowledge about the typical orientation of the two words. For the pairs that were presented in a noniconic orientation at study and iconic orientation at test, participants might have simply mistaken their stronger memory for the typical orientation of the items in the world with their memory for the orientation in which these items had actually been presented. However, this "proactive-interference" argument could not fully explain the recognition superiority of the iconic pairs. First, it suggests that participants would find the pairs presented in a noniconic orientation more salient at study because the orientation of these pairs was markedly inconsistent from their canonical one. Because distinctive items are better remembered than nondistinctive items (see Hunt & Worthen, 2006, for a review), the pairs in the salient noniconic orientation would have been better remembered than those in the iconic orientation. Contrary to this, the hit rate was indeed lower for these pairs than those pairs in the iconic orientation, even after their false-alarm difference was controlled. Second, if participants made their orientation recognition decisions based only on their knowledge about the typical orientation of the two objects, this would predict that the false-alarm rate for pairs initially studied in a noniconic orientation would be as high as the hit rate for pairs initially studied in an iconic orientation. That is, participants should be just as likely to respond "yes" to these items in the recognition test. Contrary to this, however, the hit rate for pairs studied in an iconic orientation (.78) was in fact significantly higher than the false-alarm rate for pairs studied in a noniconic orientation (.50), $t_1(59) = 7.63$, $p < .01$, $d = 1.39$; $t_2(31) = 10.46$, $p < .01$, $d = 2.62$. Hence, the "proactive-interference" argument may not be sufficient to account for the critical findings in our study.

Following Zwaan and Yaxley's (2003) interpretation, our spatial iconicity effect in relatedness judgements suggests that the visual representation of the typical orientation of the referenced objects is activated when participants judge whether the two words are related in their meanings. But as revealed by regression analyses, word-order frequency serves as a better predictor for relatedness judgement performance than spatial iconicity does. This replicates Louwerse's (2008) findings and suggests that the "spatial iconicity" effect might be influenced by word-order frequency, more than or at least equal to spatial iconicity itself. In fact, the strong influence of word-order frequency on relatedness judgements is evident in our finding that relatedness judgements were faster, and more accurate, for semantically related filler pairs than for the critical iconic pairs presented in an iconic orientation (see Table 2). In a post hoc analysis, we found that the mean word-order frequency was much higher for semantically related filler pairs ($M = 3{,}156{,}155$, median $= 782{,}786$) than for iconic pairs in iconic orientation ($M = 17{,}828$, median $= 3{,}573$), $t(58) = 2.91$, $p < .01$, $d = 0.38$, and this effect held even after we log-transformed the word-order frequencies, $t(58) = 10.12$, $p < .01$, $d = 1.33$. As we matched these two types of items on various lexical variables (see Table 1), the differences in relatedness judgement RTs and errors for these two types of pairs could be attributed to their word-order frequency difference.

According to Louwerse and Jeuniaux's (2008) symbol interdependency hypothesis, because the two words within a pair are linked with each other through higher order linguistic relationships (e.g., *car–road* is more frequently seen in this order than the reversed one, *road–car*), people may use the linguistic properties of these words to access their meanings. Reliance on the perceptually grounded representations of the two words is needed only when doing so can facilitate performance in the task. Thus, even though both embodied and linguistic representations are active in the relatedness judgement task, the linguistic representation per se exerts the most influence on participants' performance because the word-order frequency, a type of linguistic property, may be sufficient for them to determine whether two words are semantically related.

In the orientation recognition task, however, spatial iconicity predicted participants' memory performance better than word-order frequency did. Because word-order frequency is a relatively stable item difference (i.e., this variable was extracted from frequency counts in text corpora), it does not inform participants how these two words are oriented within a specific learning episode in an experimental context. In this situation, participants should rely more on the embodied representations that they encoded at study in order to make recognition decisions. This explains why perceptual simulation of spatial iconicity at study could produce a stronger effect on subsequent memory performance than do linguistic properties (i.e., word-order frequency) of the word pairs, consistent with the view that perceptual simulation occurring during online conceptual processing has a long-lasting influence on episodic memory (see also Pecher et al., 2009; Pecher et al., 2007).

Considering the dissociative effect of word-order frequency and spatial iconicity in the two tasks, we argue that even though both linguistic and embodied representations of a word pair are encoded in the relatedness judgement task and then retrieved in the subsequent orientation recognition task, they may differentially exert their effects depending on task demands. During relatedness judgements, participants rely on linguistic representations to make quick, immediate decisions about the verbal materials, whereas during orientation recognition, they rely on embodied representations that were stored and maintained over time. This idea is consistent with the symbol interdependency hypothesis, which states that symbolic representations are better relied on when engaged in tasks that assess symbolic information, such as words (Louwerse & Jeuniaux, 2008). The next question is: How do the embodied representations encoded at study facilitate recognition memory performance?

There are two ways that embodied representations (i.e., spatial iconicity of word pairs) stored at study could enhance subsequent recognition memory. First, the spatial iconicity of the word pairs at study matches participants' default attentional setting and thus directs more attentional resources towards iconic word pairs. This was supported by their faster relatedness judgements to the pairs in iconic orientation (although word-order frequency better predicts the speed at which the relatedness judgements are made). Previous studies (e.g., Estes et al., 2008) showed that object words (*eagle*), despite being presented at the centre of the screen, may trigger the perceptual simulation of its typical location (*top*) and orient participants' attention. Given that attention facilitates memory encoding (e.g., Naveh-Benjamin et al., 1998), participants may encode pairs in the iconic orientation more deeply and boost subsequent memory performance in the orientation recognition task. Second, memories that are incidentally formed via perceptual simulation during the relatedness judgement task are sensitive to overlap in perceptual simulation in the later orientation recognition task, especially when the word pairs were presented in an iconic orientation at study and at test. This was supported by our finding that orientation recognition RT was the fastest when the orientation of the pairs in the iconic condition was reinstated in the memory task. This view is analogous to the view of transfer-appropriate processing in the memory literature (e.g., Roediger, 1990; see also Pecher et al., 2009).

Another account of how embodied and symbolic representations contribute to conceptual processing is provided by Barsalou, Santos, Simmons, and Wilson's (2008) language and situated simulation (LASS) theory, which is quite similar to Louwerse's (2008; Louwerse & Jeuniaux, 2008) symbol interdependency hypothesis. This theory postulates that the processing of conceptual representations relies heavily on language and situated simulation, with situated simulation analogous to the perceptual simulation of embodied relations and language representations referring to the linguistic forms of words. According to this theory, although both the linguistic and situated simulation systems are initially activated simultaneously, when the cue is a word (as in the present study), the activation of the linguistic form peaks before the activation of situated simulations because the representation of its linguistic form is more similar to presented words than the simulations of experience (consistent with claims by Louwerse & Jeuniaux, 2008). When superficial linguistic processing is adequate to perform a task, processing relies mostly on the linguistic system and little on perceptual simulation. When linguistic processing may not support performance, the situated simulation system provides the required conceptual information. Hence, there is a time course of activation during conceptual processing: Linguistic forms come first, then embodied/situated simulation representation.

If the linguistic and situated simulation systems can directly be mapped to linguistic and embodied representations, the LASS theory might presumably account for our current findings. However, Barsalou et al. (2008) assume that the linguistic system only processes linguistic *forms* and word associations, rather than linguistic *meanings*, which are largely represented in the simulation system. To make the LASS theory work for our results, it is necessary to assume that the linguistic system is sensitive to the word-order frequency of word pairs, even though to some extent this may be related to word meanings because it largely explained the perceived semantic relatedness between words in our study. Our current finding may then reflect a timescale difference in the processing of two different configurations within the simulation system. This might suggest that both word-order frequency and spatial iconicity may affect the same situated simulation system. Nevertheless, because the present study did not directly manipulate the time course of participants' responses in the relatedness judgement and orientation recognition tasks (e.g., imposing a response deadline), it may not provide support for or against the theories that postulate the time course view that linguistic representations are activated prior to embodied representations.[4]

[4] Note that this is not problematic to our aforementioned "task-demand" view because we do not assume that the linguistic properties of word pairs have to be accessed prior to the activation of a deeper, conceptual-based situated simulation system. According to our view, it is possible that embodied experience is first accessed in the task that requires immediate judgements when the linguistic properties are not helpful in making that immediate decision. Similarly, linguistic properties can be accessed in a delayed task provided that they are more helpful than embodied experience for performing that task. This idea is consistent with Balota and Yap's flexible lexical processing framework (Balota & Yap, 2006; see also Yap, Balota, Tse, & Besner, 2008). Balota and colleagues argue that the lexical processing system is remarkably flexible and adaptive, such that it can optimize task performance by emphasizing task-relevant information. For instance, the system shows greater reliance on the semantic context (i.e., prime) as target processing becomes more difficult (e.g., presented in a degraded format) in a semantic priming paradigm.

In conclusion, most of the work on perceptual simulations provides existence proofs that perceptual simulations occur during comprehension and conceptual judgements (see a similar argument in Louwerse, 2008), but do not offer much in the way of explaining what perceptual simulations are for. In fact, we did find that word-order frequency, one of the linguistic properties for word pairs, is sufficient to explain the "spatial iconicity" effect in relatedness judgements, similar to what Louwerse reported. On the other hand, some have argued that perceptual simulations serve to prepare us for future action (Barsalou, 2008). If this is the case, then it would be fitting if memory representations are guided by these simulations. Our data support this possibility and suggest that perceptual simulations may, at least, serve a function in memory encoding, such as strengthening the memory trace (see Pecher et al., 2009, for complementary findings). Items studied in an iconic orientation facilitated memory performance compared to items studied in a noniconic orientation. Thus, the present data contribute to our knowledge of perceptual simulations and give initial evidence of how perceptual simulations may have a lasting impact on cognition.

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# APPENDIX

## Experimental stimuli

| Critical word pairs | | Filler pairs: Semantically related | | Filler pairs: Semantically unrelated | |
|---|---|---|---|---|---|
| airplane | runway | closet | hanger | algebra | silver |
| antler | deer | lobster | seafood | bounce | prison |
| attic | basement | biscuit | muffin | brush | dead |
| belt | shoe | bourbon | whiskey | cake | alike |
| billboard | highway | perfume | scent | eggs | blouse |
| boat | lake | sugar | spice | fruit | navy |
| branch | root | garlic | onion | giggle | sand |
| bridge | river | thirst | hunger | helium | gentle |
| car | road | banana | monkey | juice | watch |
| ceiling | floor | soar | eagle | music | bunny |
| cork | bottle | sport | soccer | nurse | flower |
| cup | saucer | neck | throat | price | punish |
| foam | beer | kitten | puppy | ruler | jacket |
| glass | coaster | solid | liquid | shirt | strong |
| hat | scarf | violet | purple | sketch | robber |
| head | foot | tire | rubber | sorry | grass |
| hiker | trail | drunk | alcohol | stone | brain |
| jockey | horse | funny | joke | ticket | destroy |
| kite | string | cure | disease | write | snake |
| knee | ankle | star | moon | alone | cowboy |
| monitor | keyboard | village | town | desire | garbage |
| mustache | beard | motor | engine | future | rabbit |
| pan | stove | calm | peace | lonely | toad |
| penthouse | lobby | last | final | messy | jail |
| plant | pot | sing | voice | much | sheep |
| roof | house | plain | simple | oyster | hint |
| runner | track | excuse | reason | protect | bacon |
| sky | ground | story | tell | sharp | copper |
| steeple | church | receive | give | stick | bitter |
| jam | toast | worn | used | turtle | cough |
| tractor | field | shiver | shake | water | judge |
| train | railroad | inhale | breath | weak | corn |