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Brief article

Hemispheric differences in semantic-relatedness judgments

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Abstract

Subjects judged the semantic relatedness of word pairs presented to the left or right visual field. The word pairs were presented one below the other. On critical trials, the words' referents had a typical spatial relation, with one referent oriented above the other (e.g. ATTIC/BASEMENT). The spatial relation of the words either matched or mismatched the spatial relation of their referents. When presented to the left hemisphere, the match or mismatch did not have an effect. However, there was a reliable mismatch effect for pairs presented to the right hemisphere. The results are interpreted in the context of perceptual theories of mental representation.

Keywords: Hemispheric differences; Semantic-relatedness judgments

1. Introduction

Several researchers have recently proposed perceptual theories of mental representation (e.g. Barsalou, 1999; Langacker, 1987; Paivio, 1986; Sadoski & Paivio, 2001). According to these theories, all mental representations are perception-based. Representations of people, objects, events, and their components are the residues of perceptual experience. Similarly, representations of words and their constituents (syllables, letters, phonemes) are the residues of the perceptual experience (visual, auditory, haptic, motoric) of these language units. The two types of perceptual representation are thought to be linked, such that perceptually experiencing an object may activate a word representation and reading a word may activate a perceptual representation of its referent.

In a recent study (Zwaan & Yaxley, in press), we investigated a prediction generated by perceptual symbol theories. Specifically, we examined whether semantic relations

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between words are influenced by the spatial relations between their referents. Subjects made speeded decisions of whether members of a simultaneously presented word pair were semantically related. In Experiment 1, the words were presented one above the other. In the experimental pair, the words denoted parts of larger objects (e.g. ATTIC–BASEMENT). The words were either in an iconic relation with their referents (e.g. ATTIC presented above BASEMENT) or in a reverse-iconic relation (BASEMENT above ATTIC). (Because the semantic relations between the members of a word pair can be asymmetrical, corpus analyses were conducted, which showed that the connection strengths from the "top" to the "bottom" words were not significantly stronger than those from the "bottom" to the "top" words.) The reverse-iconic condition yielded significantly slower semantic-relatedness judgments than the iconic condition. Experiments 2 and 3 showed that this effect did not occur when the words were presented horizontally, even when the arrangement of the word pairs (vertical vs. horizontal) was manipulated within subjects and within items (Experiment 3). This rules out that the observed iconicity effect was due to the order in which the words were read.

What caused this pattern? It is clear that the mismatch between the word positions and the referent positions cannot be caused by lexical associations, as these do not capture the spatial relations between the referent objects. Thus, the difference has to be attributed to differences at the level of perceptual symbols and perceptual simulations. Along with Barsalou (1999), we hypothesize that subjects, when presented with verbal stimuli such as these, engage in perceptual simulations of their referents. Take for example noses and moustaches. They are specific parts of faces. Langacker (1999) has suggested that in cases such as these, perceptual representations of the larger object of which the constituents are parts will be activated, in this example a face, with the focus on the part denoted by the noun in question (e.g. nose). This process of mental simulation will make the iconic match or mismatch between the visual representation of the words on the screen and their referents in the mental simulation available to the subject. The results of this perceptual simulation in turn influenced the semantic-relatedness judgments, such that these were faster in the case of a match than in the case of a mismatch.

However, as Zwaan and Yaxley (in press) pointed out, it is possible to conceive of an amodal explanation of these results. According to this explanation, a spatial "tag" is attached to each word based on its relative spatial position on the computer screen. Thus, the top word would get tagged with TOP. This explanation furthermore assumes that the spatial positions of objects are amodally encoded in semantic memory. Thus, for example, the concept ATTIC would have a link to the concept TOP, given that attics are typically found in the top parts of houses, whereas BASEMENT would be linked to BOTTOM. As a consequence, if a "bottom" word like BASEMENT would be presented above ATTIC, there would be a conflict between the tag assigned to it and the contents of semantic memory, thus yielding a slower response than in the case of a match.

The goal of the present study was to provide a test that would allow us to adjudicate between these two explanations. If the iconicity effect is indeed reflective of the role of perceptual symbols of the words' referents, then one would predict a hemispheric asymmetry in semantic-relatedness judgments. Specifically, given that visual-spatial relations are assumed to be stored and processed primarily in the right hemisphere (RH) (e.g. Kounios & Holcomb, 1994; Paivio, 1986, Chap. 12), the iconic match effect should at least be stronger in the RH than in the left hemisphere (LH) and maybe even be confined to the RH.

Research on semantic priming using visual field manipulations has uncovered differences between LH and RH language processing (Beeman & Chiarello, 1998; Burgess & Simpson, 1988; Chiarello, 1991; Faust & Gernsbacher, 1996; Rodel, Cook, Regard, & Landis, 1992). Linguistic stimuli typically lead to faster responses when presented to the right visual field (rvf), and thus the LH, than when presented to the left visual field (lvf), and thus the RH. More importantly, there are systematic differences between the two hemispheres with respect to semantic priming. Specifically, in the LH only a few directly relevant meanings are activated, whereas in the RH more remote semantic associations are activated (Beeman, 1998; Beeman & Bowden, 2000). The RH is therefore likely to play an important role in the generation of inferences during discourse comprehension (Beeman, Bowden, & Gernsbacher, 2000; Long & Bayes, 2002).

Just as in our earlier study (Zwaan & Yaxley, in press), our subjects were presented with two words on a computer screen, one below the other, and made speeded semantic-relatedness judgments. On critical trials, the words had referents that have a canonical vertical relation. For example, tree branches are typically above tree roots, and moustaches below noses. On Match trials, the relative positions of the words on the screen were analogous to the relative positions of their referents. Like this:

ATTIC

BASEMENT

On Mismatch trials, the relative positions of the words were in opposition to the relative positions of their referents. Like this:

BASEMENT

ATTIC

Thus, we assume that semantic-relatedness judgments are a combination of two processes: a detection of associations between perceptual representations of words and a perceptual simulation involving perceptual symbols of referents (imagens). It can be assumed that different tasks may differentially tap into these mechanisms, such that some tasks (e.g. lexical decision, naming) are likely to emphasize word associations, whereas imagery instructions should be more likely to emphasize perceptual simulations. Semantic judgments are presumably somewhere between these extremes.

2. Method

2.1. Subjects

Forty-eight Florida State University undergraduates were recruited from general psychology classes in exchange for academic course credit.

2.2. Materials

The experimental materials consisted of 128 word pairs. All words were concrete nouns ranging from one to four syllables long. Forty-four of these items were experimental word pairs consisting of the names of common objects or parts of objects that are canonically viewed in a fixed vertical orientation. For example, attics are above basements in the canonical view of a house. The remaining 84 filler items were not constrained with respect to a canonical vertical orientation of their referents. Rather the words were matched by semantic relatedness (e.g. two members of a super ordinate category, like KNIFE–FORK), or lack thereof (e.g. SALAD–RAT). These filler items consisted of 20 semantically related and 64 semantically unrelated word pairs. Thus, there were an equal number of required "yes" and "no" responses.

We entered our item pairs into the Latent-Semantic-Indexing (LSA) database (http://lsa.colorado.edu) to obtain an independent assessment of their semantic relatedness. Latent Semantic Analysis (LSA) is a mathematical/statistical technique for extracting and representing the similarity of meanings of words and passages by analysis of large bodies of text (Landauer & Dumais, 1997). The degree of semantic relatedness of a word pair is operationalized as the cosine of the contained angle of the vectors representing the meanings of words. We used LSA's pair wise comparison function, the General-Reading-up-to-1st-year-in-college-database, and the default number of factors. The average cosines were 0.40 (SD = 0.21) for the experimental pairs, 0.43 (SD = 0.21) for the semantically related filler pairs, and 0.07 (SD = 0.09) for the semantically unrelated filler pairs (there was no cosine for the pair FUTON–FENCE). The cosines for the two semantically related conditions did not differ significantly ($t(64) = -0.48$). The two semantically related conditions together had significantly higher cosines than the unrelated filler pairs ($t(77.16) = 12.18$, $P < 0.0001$), with the number of degrees of freedom being adjusted for the inequality of variances.

2.3. Design and procedure

Two main factors, spatial orientation and visual hemifield, were manipulated within subjects and within items. In what follows, we will refer to these as Match and Hemisphere for ease of exposition (despite the fact that visual field rather than hemisphere was the manipulated variable). Four lists were created to counterbalance items and conditions. Each list included one of four possible versions (2 Match × 2 Hemisphere). Each participant saw only one list. This produced a 2 (match vs. mismatch) × 2 (LH vs. RH) design.

Stimuli were presented by a PC on a 19 inch display using the E-Prime (2000) stimulus presentation software. Participants were instructed to read the word pairs that appeared briefly on the screen and judge whether the words were semantically related. Furthermore, they were informed that the relations between the words should be evident, as the task was not designed to be deceptive. Participants were further instructed that response times and accuracy scores would be recorded. Therefore, they should keep their index fingers positioned on the response keys at all times during the experiment to enable quick and accurate responses. The j- and f-keys were labeled "Y" and "N", respectively. Responses not made within 2 s after stimulus presentation were logged as incorrect and the following trial was

Table 1
Semantic-relatedness judgment latencies and accuracy segregated by match condition and hemisphere (standard deviations in parentheses)

	LH/rvf		RH/lvf	
	Latency	Accuracy	Latency	Accuracy
Match	775 (166)	0.87 (0.11)	780 (156)	0.80 (0.10)
Mismatch	773 (161)	0.85 (0.11)	822 (165)	0.80 (0.12)

cued. The middle of each stimulus word was presented at 2.67° of visual angle from the fixation point. On average, the right-most letter of a lvf presented word or the left-most letter of a rvf presented word was 1.49° of visual angle from the fixation point. Each word pair subtended 1.34° of vertical visual angle at a viewing distance of 60 cm.

During the reading of text, information from below the fixation typically is not used (Inhoff & Brühl, 1991; Pollatsek, Raney, LaGasse, & Rayner, 1993). However, our stimuli did not necessitate horizontal eye movements as in reading lines of text and the vertically arranged words were relevant to each other in the context of the task (unlike in reading normal text). We provided practice items so that the subjects could get used to the task and could attend to both words in a single fixation. Four practice items were presented at the beginning of the experiment. These items consisted of two semantically related and two semantically unrelated word pairs. Most participants seemed adequately proficient at the task after completing these four practice trials.

The two factors, Match and Hemisphere, were manipulated by controlling word placement on the screen. This was achieved by defining four invisible cells on the screen space and presenting each word in one of these cells by condition. In the vertical partition, the cells were approximately 2.5 mm above or below the center of the screen. Both words of each were presented either to the right (rvf) or the left (lvf) of the center of the screen. Four lists were created with each list having equal numbers of items in each cell of the design and conditions counterbalanced across lists. Each subject was exposed to only one list and equal numbers of subjects were allocated to each list. Participants controlled the inter-trial interval and initiated each trial by pressing the spacebar. At the start of each trial, a centrally located fixation cross was presented for 250 ms. Then each word pair was displayed for 200 ms in two of the four cells. This value was chosen based on pilot research. It allowed a sufficient number of subjects to identify both words, but did not provide them with enough time to re-fixate the words after a saccade.

Participants were forced to make their judgment of semantic relatedness within 2 s. Response latencies and semantic-relatedness judgments were recorded via the keyboard using the J-key for "yes" responses and the F-key for "no" responses. The entire process required approximately 15 min (Table 1).

3. Results

Subjects with <50% accuracy in one or more conditions were replaced. About half the subjects we ran initially had to be replaced. This is not surprising, given the fact that the two words were presented for only 200 ms and given the nature of our subject pool, whose members exhibit a wide range of verbal abilities. All analyses involve data from subjects with accuracy scores >55% in each condition (and >70% overall). Latencies <200 ms and >1700 ms were considered outliers. In addition, latencies more than two standard deviations from a subject's mean were discarded. In total less than 3% of the data were excluded.

Two mixed analyses of variance (ANOVAs) were conducted. Hemisphere and Match were varied within subjects and items, respectively, whereas List was manipulated between subjects and items. Analyses against subject variability are indicated with the subscript 1 and analyses against item variability with the subscript 2.

There was a significant effect of Hemisphere ($F_1(1,44) = 4.80$, $P < 0.05$, MSe = 7242; $F_2(1,40) = 13.63$, $P < 0.001$, MSe = 3214), with the LH generally being faster than the RH. There also was an effect of Match ($F_1(1,44) = 4.36$, $P < 0.05$, MSe = 4351; $F_2(1,40) = 4.72$, $P < 0.05$, MSe = 4951). In addition, there was an interaction between these two factors ($F_1(1,44) = 3.48$, $P < 0.07$, MSe = 6941; $F_2(1,40) = 4.89$, $P < 0.05$, MSe = 4621). To examine the interaction more closely, we analyzed the data for each hemisphere separately. As predicted, there was no hint of a Match effect in the LH (both Fs < 1), whereas there was a significant effect in the RH ($F_1(1,44) = 6.73$, $P < 0.015$; $F_2(1,40) = 9.62$, $P < 0.005$), with the Match condition being faster than the Mismatch condition. In addition, the Mismatch condition in the RH was significantly slower than its LH counterpart ($F_1(1,44) = 8.26$, $P < 0.01$, MSe = 7064; $F_2(1,40) = 14.78$, $P < 0.0001$, MSe = 4384), whereas the two Match conditions were equivalent across hemispheres (both Fs < 1). In addition to being faster overall, the LH was also more accurate than the RH ($F_1(1,44) = 12.07$, $P < 0.01$, MSe = 0.0134; $F_2(1,40) = 12.01$, MSe = 0.0118). There were no other significant effects on accuracy (all Fs < 1).

4. Discussion

These results extend our earlier findings (Zwaan & Yaxley, in press). The extent to which the spatial configuration of words on a screen matches that of their referents affects semantic-relatedness judgments. Our present findings show that the mismatch effect is confined to the RH. These results are consistent with perceptual symbol theories (e.g. Barsalou, 1999; Langacker, 1987; Paivio, 1986; Pulvermüller, 1999; Sadoski & Paivio, 2001; Tranel, Damasio, & Damasio, 1997).

The fact that the Mismatch condition in the RH yielded longer response times than its counterpart in the LH could be interpreted to suggest that the elevated reaction times were due to interference between the perceptual representation derived from viewing the words on the screen and that derived from simulating their referents. Alternatively, it is possible that the pattern of results is due to facilitation in the RH-match condition, given that (1) LH responses tend to be faster than RH responses to verbal stimuli (e.g. Chiarello, 1991) and (2) LH and RH were equally fast in the Match condition in the present experiment. This explanation would suggest that the expected difference between LH and RH for the Match pairs was eliminated by the perceptual facilitation in the RH. Our current data do not allow us to adjudicate between these two potential explanations. However, they do make it clear that a match or mismatch between verbal stimulus configurations and that of their referents affects semantic-relatedness judgments made by the RH.

The current findings cast a new light on hemispheric differences in word-based priming. The coarse semantic coding hypothesis (Beeman, 1998) argues that the RH is engaged in coarse coding and thus is sensitive to more remote semantic relations than the LH, which specializes in a specific coding of semantic relations. Though our present results do not rule out this hypothesis, they do show that there is more to inter-hemispheric differences than merely a difference in coarseness of semantic coding. The strength of semantic associations was perfectly controlled for in our word pairs; after all, only their respective positions on the computer screen were manipulated.

To summarize, our results are consistent with a prediction derived from perceptual symbol theories and as such add to the mounting psycholinguistic evidence in support of these theories (Dahan & Tanenhaus, 2002; Glenberg & Kaschak, 2002; Pecher, Zeelenberg, & Barsalou, in press; Stanfield & Zwaan, 2001; Zwaan, Stanfield, & Yaxley, 2002; Zwaan & Yaxley, in press). The puzzle for future research is to figure out exactly how perceptual simulations are guided by language. This is a daunting but also exciting task for researchers in the field.

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