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## Effect of Representational Distance Between Meanings on Recognition of Ambiguous Spoken Words

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### Abstract

Previous research indicates that mental representations of word meanings are distributed along both semantic and syntactic dimensions such that nouns and verbs are relatively distinct from one another. Two experiments examined the effect of representational distance between meanings on recognition of ambiguous spoken words by comparing recognition of unambiguous words, noun–verb homonyms, and noun–noun homonyms. In Experiment 1, auditory lexical decision was fastest for unambiguous words, slower for noun–verb homonyms, and slowest for noun–noun homonyms. In Experiment 2, response times for matching spoken words to pictures followed the same pattern and eye fixation time courses revealed converging, gradual time course differences between conditions. These results indicate greater competition between meanings of ambiguous words when the meanings are from the same grammatical class (noun–noun homonyms) than when they are from different grammatical classes (noun–verb homonyms).

*Keywords:* Ambiguity resolution; Homonyms; Homophones; Spoken word recognition; Eye tracking; Semantic distance; Grammatical class

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### 1. Introduction

Many words are globally ambiguous: The same written or spoken form can have multiple senses, and often completely different meanings. Resolving this ambiguity is critical for successful language comprehension, so understanding ambiguity resolution is critical for understanding language processing. One crucial factor governing ambiguity resolution is

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semantic distance between meanings of ambiguous words. Rodd, Gaskell, and Marslen-Wilson (2002) found that words with many similar meanings (e.g., *belt*) are recognized more quickly than words with few similar meanings (e.g., *bone*), and words with many dissimilar meanings (e.g., *bark*) are recognized more slowly than words with few dissimilar meanings (e.g., *bend*). That is, ambiguity at small semantic distances speeds word recognition, and ambiguity at large semantic distances slows word recognition. This complex pattern emerges naturally in attractor dynamical models because similar meanings cluster to form large attractors, and such models settle more quickly to large attractors; dissimilar meanings form conflicting attractors, and this conflict slows down the settling process (Rodd, Gaskell, & Marslen-Wilson, 2004).

Semantic distance also affects the magnitude of semantic priming: Words that are more closely semantically related are stronger primes (e.g., Cree, McRae, & McNorgan, 1999). Syntactic distance also affects prime strength. For example, Vigliocco, Vinson, Arciuli, and Barber (2008) presented noun and verb primes for verb targets with and without a minimal phrasal context (“the” + noun vs. “to” + verb). Noun and verb primes were matched at high or low semantic similarity to targets. When phrasal context was included, there were independent influences of grammatical category and relatedness, and no interaction. When primes had very low similarity to targets, recognition of verb targets was faster following verb primes than noun primes only when the primes were presented in a phrasal context, suggesting that syntactic features are not activated when a bare word is encountered. Similarly, verb distractors interfere with action naming using the inflected form (Vigliocco, Vinson, & Siri, 2005). These findings suggest that mental representations of nouns and verbs may be fundamentally distinct from one another, especially when a phrasal context is present to increase syntactic dissimilarity. However, verbs prime their typical agents, patients, and instruments (Ferretti, McRae, & Hatherell, 2001) and vice versa (McRae, Hare, Elman, & Ferretti, 2005), consistent with an event-based view of word meaning representations that precludes completely distinct stores for verb and noun meanings.

The hypothesis that nouns and verbs have relatively distinct representations is also consistent with a large body of neuropsychological, functional imaging, and computational modeling studies. Some researchers have argued that this representational distinction is fundamentally due to grammatical class (e.g., Shapiro & Caramazza, 2003), but others have argued it is due to a semantic sensory/motor distinction (e.g., Lo Gerfo et al., 2008; Vigliocco et al., 2006). Because nouns and verbs tend to occur in different relative positions in a sentence, internal representations learned by recurrent neural networks cluster by grammatical class (Elman, 1990). Such simulations suggest that statistical properties of noun and verb usage—independent of meaning or the abstract construct of grammatical class—are sufficient to produce relatively distinct representations for nouns and verbs. In addition, models based only on distributional properties of word usage can account for a tremendous amount of semantic processing data (e.g., Landauer & Dumais, 1997), and models that are sensitive to such properties develop representations that cluster along both semantic and syntactic dimensions (e.g., Elman, 1990).

The picture that emerges from this complex pattern of results is that there is a continuous representational space for all lexical dimensions. There are not separate stores for nouns and verbs; rather, word meanings spread continuously in this space according to both semantic and syntactic similarity (as well as other dimensions, such as phonology and orthography). Even though the system is sensitive to discrete manipulations of one dimension, the dimensions are not instantiated discretely, but on a common computational substrate (e.g., Elman, 1990, 2004), such that distances between representations of word meanings are a function of semantic *and* syntactic similarity (among other dimensions). Thus, when we refer to representational distance, we mean distance in continuous, multi-dimensional space.

For words with multiple meanings or senses, this view defines four general levels of representational distance: (a) the closest representations are for similar senses that are in the same syntactic category (e.g., *belt-clothing*, *belt-mechanical*); (b) denominal verbs and their root nouns (such as *hammer*) are slightly farther apart because they are closely related semantically and thematically, but differ in syntactic features; (c) words with unrelated meanings that belong to the same syntactic class (e.g., *deck-cards*, *deck-boat*) are even farther apart; and (d) words with unrelated meanings from different syntactic categories are farthest apart (e.g., *bark-tree*, *bark-dog*).

Level 1 (and possibly level 2) corresponds to polysemy, where high phonological and semantic similarity appear to drive facilitative gang effects (Rodd et al., 2002). Levels 3 and 4 correspond to ambiguity, where lexical activation is typically slowed (presumably because it takes time for semantic features to override extreme phonological similarity; Rodd et al., 2002). Rodd et al. demonstrated the different effects of multiple meanings at near (levels 1 and 2) and far (levels 3 and 4) representational distances. In the present experiments, we investigated the possible further effect of differences in representational distance between levels 3 and 4. Specifically, we compared recognition of unambiguous spoken words to recognition of ambiguous words that had either two noun meanings or one noun meaning and one verb meaning. Experiment 1 used an auditory lexical decision task; Experiment 2 used the visual world eye-tracking paradigm in order to seek converging evidence and to examine the time course of the effect.

## 2. Experiment 1

### 2.1. Method

#### 2.1.1. Participants

Forty University of Connecticut undergraduates participated for course credit. All reported English as their native language, with no history of hearing impairments.

#### 2.1.2. Stimuli and procedure

The critical stimuli were 13 balanced noun–noun homonyms (e.g., *deck-cards*, *deck-boat*), 13 balanced noun–verb homonyms (e.g., *bark-tree*, *bark-dog*), and 16 unambiguous words (e.g., *acorn*). The stimulus list was built by starting with all of the homonyms

that had entries in the American National Corpus (ANC; Ide & Suderman, 2004; for matching on control variables) and the University of South Florida Free Association Norms (Nelson, McEvoy, & Schreiber, 2004) and that had at least one easily picturable noun meaning (required for Experiment 2). A meaning was defined as a separate entry in the *Oxford English Dictionary* (OED, <http://www.oed.com>) and meaning dominance was assessed based on proportion of related associates in the association norms. For example, according to the USF Free Association Norms, the associates of “chest” can be grouped under three of the meanings listed in the OED: thorax (rib, breast, hairy, etc.; comprising 29.9% of responses), coffer (treasure, trunk, etc.; comprising 30.2% of responses), and furniture (drawer, dresser, and bureau; comprising 15.3% of responses). Thus, “chest” was categorized as a balanced noun–noun homonym, because no single meaning had greater than 75% of responses and more than 90% of the responses were associates of noun meanings. Note that the OED does list verb meanings for “chest” (to put in a coffin; to enclose in a box; of a horse, to strike with the chest); however (in addition to being rare if not archaic), these meanings are clearly derived from the noun meanings and none of the associates specifically referred to action meanings. In general, denominal verb meanings were considered part of their appropriate noun meaning (because they are so strongly related semantically and thematically) and meanings that were related to <5% of associates were not considered when assigning words to conditions.

After splitting homonyms into noun–noun and noun–verb conditions, the word lists were pruned and a list of unambiguous words was collected so that there would be no overall differences between conditions in cumulative word frequency, neighborhood and cohort density,<sup>1</sup> uniqueness point, and length in syllables, phonemes, and duration of the recorded stimulus word. Word frequency (normalized to occurrences per 1 million word tokens) and other lexical variables were computed using the ANC (Ide & Suderman, 2004), a large-scale, representative corpus of American English containing over 3.2 million spoken word tokens. See Table 1 for values of lexical variables and Appendix A for the complete set of critical stimuli. Nonwords were constrained to be consistent with American English phonotactics and matched in length to the words. There were two versions of Experiment 1 that differed only in the filler stimuli. The first version was designed in anticipation of Experiment 2, which was constrained to only highly imageable nouns, so the filler stimuli were 42

Table 1

Lexical properties of critical words: Means for controlled variables and standard deviations in parentheses

Property	Noun–Noun	Noun–Verb	Unambiguous
Word frequency	17.3 (27.5)	20.4 (23.3)	17.9 (25.3)
Neighborhood density	12.6 (10.2)	15.0 (13.1)	15.0 (14.1)
Cohort density	48.4 (33.3)	46.9 (36.9)	47.3 (37.6)
Uniqueness point	4.00 (0.82)	4.00 (1.15)	3.63 (1.02)
No. syllables	1.23 (0.44)	1.31 (0.63)	1.38 (0.50)
No. phonemes	4.00 (0.82)	4.00 (1.15)	3.75 (1.18)
Duration (ms)	608.2 (108)	603.5 (87.2)	603.4 (78.0)

unambiguous highly imageable nouns and 84 nonwords. Twenty-four participants completed this version of the experiment. The second version was designed to shift attention away from highly imageable meanings, so the filler stimuli were 83 low-imageability words and 125 nonwords (for evidence of attention shifting by filler lists see, e.g., Mirman, McClelland, Holt, & Magnuson, 2008; Monsell, Patterson, Graham, Hughes, & Milroy, 1992). Sixteen participants completed this version. Thus, both versions were composed of 50% words and 50% nonwords; the only difference was the proportion of words that were imageable (version 1: 100%; version 2: 34%). However, a 2 (versions) by 3 (word conditions) ANOVA showed no evidence of a main effect or interaction with version, so the data were combined and the overall results will be presented.

All stimuli were produced by a female native speaker of American English in a sound-attenuated room and digitized at 44 kHz.

Participants used the keyboard (“A” and “L” keys) to indicate whether each stimulus was a real English word (i.e., auditory lexical decision). Stimuli were presented through headphones at comfortable listening volume. The experiment began with 40 practice trials (20 words and 20 nonwords in random order) with feedback to familiarize participants with the task. There was a 1-s delay between the end of a trial (participant’s response) and the start of the next trial.

## 2.2. Results and discussion

Overall accuracy was very high, though it was slightly lower for the noun–noun condition ( $M = 94.0$ ,  $SD = 0.07$ ) relative to the noun–verb [ $M = 97.1$ ,  $SD = 0.05$ ; by subjects:  $t(39) = 2.0$ ,  $p < .05$ ; by items:  $t(24) = 1.4$ ,  $p = .19$ ] and unambiguous [ $M = 97.0$ ,  $SD = 0.01$ ; by subjects:  $t(39) = 2.3$ ,  $p < .05$ ; by items:  $t(27) = 1.3$ ,  $p = .21$ ] conditions; the very small difference between noun–verb and unambiguous conditions was not reliable [by subjects:  $t(39) = 0.1$ ,  $p = .91$ ; by items:  $t(27) = 0.1$ ,  $p = .96$ ]. Response time was measured from word onset and only correct response trials were included in the response time analyses. To minimize the impact of outliers without relying on arbitrary exclusion criteria or transforming the data, response time medians were analyzed<sup>2</sup> (cf. Ratcliff, 1993). Fig. 1 shows a clear graded pattern in response times: Unambiguous words were recognized most quickly, noun–verb homonyms somewhat slower [by subjects:  $t(39) = 3.8$ ,  $p < .001$ ; by items:  $t(27) = 1.1$ ,  $p > .25$ ], and noun–noun homonyms slowest [compared to noun–verb homonyms: by subjects:  $t(39) = 4.5$ ,  $p < .0001$ ; by items:  $t(24) = 2.0$ ,  $p = .05$ ; compared to unambiguous words:  $t(39) = 9.2$ ,  $p < .0001$ ; by items:  $t(27) = 3.9$ ,  $p < .001$ ].

These results replicate the previous finding of an ambiguity disadvantage (e.g., Rodd et al., 2002): Words with multiple meanings were recognized more slowly than words with only one meaning. More importantly, the ambiguity disadvantage was greater for noun–noun homonyms than for noun–verb homonyms. Previous studies (e.g., Vigliocco et al., 2005, 2008) suggested that the representational distance between meanings within grammatical class (i.e., two noun meanings) is smaller than the distance between meanings across grammatical class (i.e., a noun meaning and a verb meaning); the present results suggest that this reduced representational distance causes an increase in the competition between

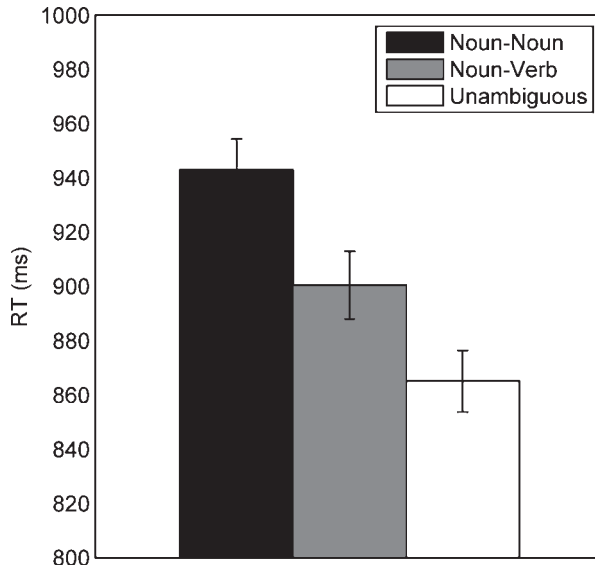


Fig. 1. Experiment 1 response time results. Error bars indicate  $\pm$  SE.

meanings for ambiguous words. Experiment 2 was designed to test for converging evidence using the same critical words but with the visual world eye-tracking paradigm, which forces recognition of a specific meaning and provides an estimate of the time course of processing.

### 3. Experiment 2

In Experiment 2, recognition of the same critical spoken words was tested using the visual world eye-tracking paradigm (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995), which provides an important extension to Experiment 1. The visual world eye-tracking paradigm has a different set of task constraints, thus providing an important alternative examination of the effect of representational distance on ambiguity resolution. In particular, lexical decision may be performed without semantic access, merely on the basis of perceptual familiarity (e.g., Rogers, Lambon Ralph, Hodges, & Patterson, 2004), and responses for ambiguous words may be due to activation of either possible meaning (e.g., Dahan, Magnuson, Tanenhaus, & Hogan, 2001). In contrast, the visual world paradigm task requires activation of a specific target meaning in order to perform the task correctly.

#### 3.1. Method

##### 3.1.1. Participants

Eighteen University of Connecticut undergraduates participated for course credit (two additional participants were excluded due to technical problems). All reported English as

their native language, and normal hearing and normal vision (due to the low probability of obtaining sufficiently accurate eye tracker calibrations with subjects wearing glasses or contact lenses, these participants were excluded).

### 3.1.2. Materials and procedure

The auditory materials were the same as those used in Experiment 1. On each trial, participants saw four images on a 17" screen: the target image and three unrelated distractor images. Distractors were chosen to be phonologically unrelated (not sharing initial phoneme or a rime) and semantically unrelated (not a semantic associate or a category coordinate). Images were collected from an image database or from a Web search. Each image was presented near one of the screen corners, 15% of the screen size away from the horizontal and vertical edge of the screen; images had a maximum size of  $200 \times 200$  pixels and were scaled so that at least one dimension was 200 pixels. Screen resolution was set to  $1024 \times 768$ . Image position was assigned randomly on each trial. Gaze position and duration were recorded using an ASL 6000 remote eye-tracker (Applied Science Laboratories, Bedford, MA). Each trial began with a 500-ms preview of the four images. If initial eye movements were driven by visual salience rather than linguistic input, this preview period would reveal such effects before the onset of the speech signal (no such baseline differences were observed). At the end of the preview period the target word was presented through headphones and participants had to use the mouse to click on the image corresponding to the target word. The experiment began with 12 practice trials on which feedback was presented.

### 3.2. Results and discussion

Participants did not make any errors in any of the conditions. Mouse click response time was measured from word onset. As in Experiment 1, response time medians were analyzed to minimize the impact of outliers. The response time pattern mirrored the graded pattern found in Experiment 1: Unambiguous words were recognized most quickly ( $M = 1162.7$  ms,  $SD = 139.0$ ), noun-verb homonyms somewhat slower [ $M = 1256.7$  ms,  $SD = 139.5$ ; by subjects:  $t(17) = 4.0$ ,  $p < .001$ ; by items:  $t(27) = 1.9$ ,  $p = .07$ ], and noun-noun homonyms slowest [ $M = 1394.8$  ms,  $SD = 185.5$ ; compared to noun-verb homonyms: by subjects:  $t(17) = 5.7$ ,  $p < .0001$ ; by items:  $t(24) = 2.4$ ,  $p < .05$ ; compared to unambiguous words:  $t(17) = 9.5$ ,  $p < .0001$ ; by items:  $t(27) = 3.8$ ,  $p < .001$ ].

Fig. 2 shows the target image fixation time course for the three conditions. Speed of spoken word processing is reflected by three closely related aspects of fixation curves: (a) narrowness (depending on time to look to and then away from targets); (b) height; and (c) time of the peak. Although it is hypothetically possible for these aspects to be independent, the task constraints of this experiment result in curves for each condition having the same characteristic shape, thus the speed of word recognition is simultaneously reflected in all three. The time course data converged with the response time data: The time course of word recognition was the fastest for unambiguous words, slower for noun-verb homonyms, and slowest for noun-noun homonyms. Growth curve analysis (Mirman, Dixon, & Magnuson, 2008) was used to quantify these condition differences. The target fixation curve was

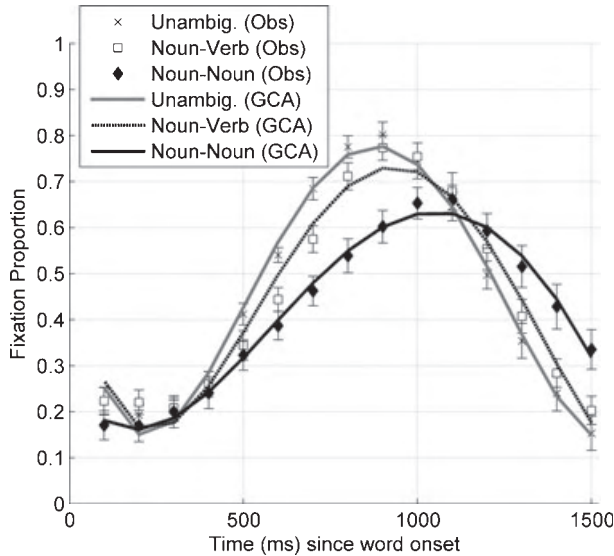


Fig. 2. Time course of target fixation in Experiment 2. Symbols indicate observed data (error bars indicate  $\pm$  SE), and lines show the fit of the growth curve analysis model.

modeled by a fourth-order polynomial including individual subject effects on each of the polynomial time factors (fourth-order is required to capture the three inflection points of the curve; see Mirman, Dixon, & Magnuson, 2008, for details). Condition effects were evaluated based on their effects on parameters of the target fixation curves. A condition effect on fixation time course would have the biggest influence on the second-order time parameter; that is, an effect of condition on the roughly parabolic width of the fixation proportion curve (with height and time of peak closely related to width). Separate by-subjects and by-items growth curve analyses were carried out. By-subjects model fit is superimposed on the behavioral data in Fig. 2, and growth curve analysis revealed that the strongest effect of condition was on the quadratic term [NN–NV, by subjects  $t(676) = 7.87$ ,  $p < .0001$ , by items  $t(576) = 5.29$ ,  $p < .0001$ ; NN–U, by subjects  $t(676) = 12.05$ ,  $p < .0001$ , by items  $t(576) = 8.58$ ,  $p < .0001$ ; NV–U, by subjects  $t(428) = 4.65$ ,  $p < .0001$ , by items  $t(398) = 2.93$ ,  $p < .01$ ; full statistical results are available in Appendix B], indicating a fastest time course for recognition of unambiguous words, slower recognition of noun–verb homonyms, and slowest recognition of noun–noun homonyms.

In Experiment 2, the visual world paradigm was used to extend the similar auditory lexical decision findings from Experiment 1. By using a naturalistic linguistically guided visual search task, Experiment 2 avoided the task demands of auditory lexical decision, thus showing that the results were not due to low-level familiarity differences or responses due to activation of the non-target meaning of ambiguous words. In addition, by measuring fixation likelihoods throughout the trial, Experiment 2 revealed that differences between word conditions evolve gradually over the time course. The gradual time course effect suggests that



greater representational distance between nouns and verbs reduces competition between meanings.

#### **4. General discussion**

Two experiments compared recognition of ambiguous spoken words that had two noun meanings to words that had one common noun meaning and one common verb meaning. In Experiment 1, lexical decision was slower for ambiguous words than unambiguous words, and slower for noun–noun homonyms than noun–verb homonyms. In Experiment 2, listeners were slower to find a named picture when the name was ambiguous than when it was unambiguous, and slower for noun–noun homonyms than noun–verb homonyms. Further, fixation time course data indicated a gradual effect of grammatical class, suggesting that differences in word recognition time were due to online ambiguity resolution. The converging results from two very different experimental paradigms—lexical decision and word-picture matching—indicate that the findings reflect a general property of word recognition. Together, these two experiments indicate that competition between meanings is greater within than between grammatical classes.

Recent behavioral findings suggest that verbs are more strongly related to other verbs than to nouns (e.g., Vigliocco et al., 2005, 2008). Neural evidence also suggests that nouns and verbs may have relatively distinct representations (e.g., Lo Gerfo et al., 2008; Shapiro & Caramazza, 2003; Vigliocco et al., 2006). However, isolated verbs do prime typical agents and patients and vice-versa (Ferretti et al., 2001; McRae et al., 2005), suggesting that strong semantic and thematic relations can overcome syntactic distance to cause priming across grammatical class boundaries. Simulations using recurrent connectionist networks (Elman, 1990, 2004) show that statistical properties of noun and verb usage are sufficient to produce distinct representational grouping of nouns and verbs without distinct representational substrates. The current results suggest that greater representational distance between nouns and verbs reduces competition between the meanings of an ambiguous word when they are from different grammatical classes.

Semantic distance between meanings has emerged as a critical aspect of ambiguity resolution (Rodd et al., 2002, 2004). Words with multiple closely related meanings are recognized more quickly than unambiguous words, and words with multiple unrelated meanings are recognized more slowly than unambiguous words (Rodd et al., 2002). This pattern suggests facilitation due to similar meanings and competition among dissimilar meanings (Rodd et al., 2004). The present results suggest that when unrelated meanings are even more distinct—when they are from different grammatical classes—competition is reduced. Fig. 3 shows a schematic of the proposed relationship between representational distance and the effect of ambiguity on word recognition. The left end shows the facilitative effect of polysemy (multiple similar meanings) demonstrated by Rodd et al. (2002) and others. The middle portion shows the inhibitory effect of multiple dissimilar within-class meanings found in the noun–noun homonym condition of the present experiments and demonstrated by Rodd et al. (2002) and others. The right end shows the decreased inhibitory effect of multiple

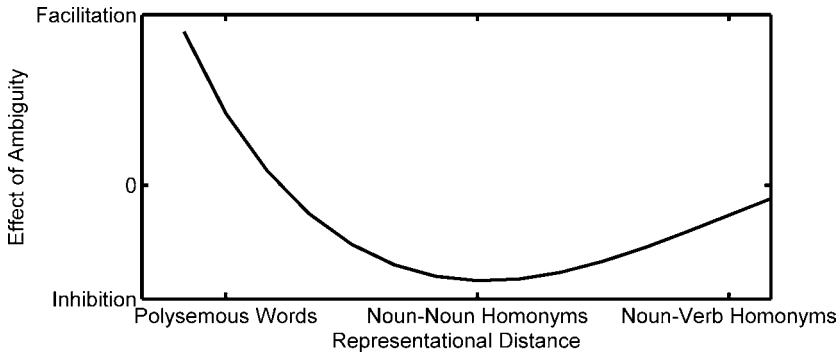


Fig. 3. Schematic depiction of proposed relationship between representational distance and effect of ambiguity on word recognition.

dissimilar between-class meanings found in the noun–verb homonym condition of the present experiments. A natural complementary prediction from this view is that Verb–Verb ambiguous words (e.g., *rap*—*wrap*) should also be recognized more slowly than noun–verb ambiguous words.

Like recent priming and interference studies (Vigliocco et al., 2005, 2008), the present results demonstrate an effect of syntactic distance, but without the minimal phrasal contexts that were necessary in past studies to reveal such effects. At the most general level, our results demonstrate that a phrasal context is not required to reveal syntactic similarity effects, though context may strengthen such effects, as predicted on constraint-based theories (e.g., MacDonald, Pearlmutter, & Seidenberg, 1994; Trueswell & Tanenhaus, 1994). Differences between our results and those of Vigliocco et al. might stem in part from our use of nouns versus their use of verbs as targets, or our use of auditory lexical decision and the visual world paradigm versus their use of priming and interference paradigms. The visual world paradigm, in particular, may be more sensitive to syntactic distance effects, just as it is more sensitive than priming paradigms to phonological competition (Allopenna, Magnuson, & Tanenhaus, 1998) and subtle semantic overlap (Mirman & Magnuson, 2009).

Another crucial difference is that primes used in previous studies were phonologically unrelated to targets. On the view that all lexical dimensions share the same representational substrate (Elman, 1990, 2004), phonological distance will influence one’s ability to detect effects of distance on other dimensions. By using homonyms, we were able to examine effects of syntactic and semantic distance with phonological distance held constant at zero. In so doing, we were able to detect new subtleties of lexical memory: The degree of competition exerted by words with identical phonological forms depends not only just upon semantic distance (e.g., Rodd et al., 2002) but also syntactic distance, such that greater syntactic distance reduces competition. This also demonstrates that syntactic features are intrinsic to lexical memory and are activated automatically even in the absence of syntactic class-specific phrase cues or need for syntactic integration (as in sentence processing).

The present results add to the growing set of findings that describe the dynamics of traversing a continuous, multidimensional representational space during word recognition. When word form is held constant (i.e., homophones/homonyms), these dynamics include the polysemy advantage and ambiguity disadvantage (Rodd et al., 2002) and the present finding that syntactic distance mitigates the ambiguity disadvantage. When word form is allowed to vary, these dynamics include activation of concepts that share semantic and/or syntactic features (e.g., Cree et al., 1999; Mirman & Magnuson, 2009; Vigliocco et al., 2008), activation of thematically related concepts (Ferretti et al., 2001; McRae et al., 2005), and slowing of word recognition by highly semantically similar concepts and speeding of word recognition by moderately semantically similar concepts (Mirman & Magnuson, 2008). These empirical characterizations of the dynamics of word processing provide critical constraints on future development of models of word recognition and language processing.

## Notes

1. Neighborhood density was defined as the summed log-frequency of words differing by a single phoneme (Luce & Pisoni, 1998), and cohort density as the summed log-frequency of words with the same onset (Magnuson, Dixon, Tanenhaus, & Aslin, 2007).
2. Similar results were obtained when means of inverse-transformed response times were analyzed or when outliers ( $>4 SD$  above the mean) were excluded.

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## Appendix A: Critical stimuli

Noun–noun homonyms: bolt, chest, court, crane, deck, fan, glass, mint, organ, palm, ruler, straw, temple.

Noun–verb homonyms: bark, bowl, count, fly, hamper, park, prune, register, ring, seal, shed, swallow, train.

Unambiguous words: acorn, doctor, groom, hammer, knife, lobster, lock, map, mug, pie, scissors, skirt, sock, tape, tie, window.

## Appendix B: Growth curve analysis model fit results for Experiment 2

Noun–Noun homonyms condition was used as the baseline. Separate by-subjects and by-items growth curve analyses were carried out and the results for both analyses are shown.

Term	Noun–Verb			Unambiguous			Noun–Verb versus Unambiguous		
	Estimate	<i>t</i>	<i>p</i>	Estimate	<i>t</i>	<i>p</i>	Estimate	<i>t</i>	<i>p</i>
Intercept									
Subjects	0.0241	2.05	<.05	0.0301	2.56	<.05	0.0060	0.63	n.s.
Items	0.0262	1.31	n.s.	0.0323	1.71	<.1	0.0062	0.32	n.s.
Linear									
Subjects	−0.1883	3.43	<.001	−0.2783	5.07	<.0001	−0.0900	1.97	<.05
Items	−0.1763	1.48	n.s.	−0.2671	2.36	<.05	−0.0908	0.77	n.s.
Quadratic									
Subjects	−0.2416	7.87	<.0001	−0.3699	12.05	<.0001	−0.1283	4.65	<.0001
Items	−0.2364	5.29	<.0001	−0.3647	8.58	<.0001	−0.1283	2.93	<.01
Cubic									
Subjects	−0.0775	2.53	<.05	−0.0079	0.26	n.s.	0.0697	2.53	<.05
Items	−0.0791	1.77	<.1	−0.0096	0.23	n.s.	0.0695	1.59	n.s.
Quartic									
Subjects	0.1562	5.09	<.0001	0.2421	7.89	<.0001	0.0858	3.11	<.01
Items	0.1530	3.42	<.001	0.2399	5.64	<.0001	0.0869	1.99	<.05