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Long-term priming of the meanings of ambiguous words

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ABSTRACT

Comprehension of semantically ambiguous words (e.g., "bark") is strongly influenced by the relative frequencies of their meanings, such that listeners are biased towards retrieving the most frequent meaning. These biases are often assumed to reflect a highly stable property of an individual's long-term lexical–semantic representations. We present three experiments that support an alternative view and suggest that these biases reflect a highly flexible aspect of lexical representations. We show that a single encounter with an ambiguous word in context is sufficient to bias a listener's interpretation of that word after an average delay of more than 20 min. This word-meaning priming effect is not affected by changes to the speakers' identity between initial exposure and later testing, and is longer-lasting than purely semantic priming without the presence of the ambiguous word. These results provide evidence for a top-down influence of sentential context in retuning abstract lexical/semantic representations, and illustrate how semantic retuning can improve the comprehension of ambiguous words in speech.

Introduction

Understanding natural speech requires that we retrieve and combine the meanings of individual words so as to construct a representation of the meaning of a whole sentence. The presence of ambiguous words (e.g., *bark*) makes these processes more difficult since the listener must use contextual information to identify the appropriate meaning (e.g., "*bark* of a dog/tree"). Semantic ambiguity is ubiquitous in language, with over 80% of common English words having more than one dictionary definition (Rodd, Gaskell, & Marslen-Wilson, 2002). The cognitive processes involved in ambiguity resolution form a critical, and much studied, part of our language comprehension system (see Twilley & Dixon, 2000).

One factor that is known to be important in this disambiguation process is the relative frequencies of the ambiguous word's different meanings, also known as dominance. For example the word "pen" has a high-frequency meaning (a writing implement) and a low-frequency meaning (enclosure for animals). In simple word association tasks (in the absence of any relevant context) participants are biased to retrieve the word's more frequent meaning (e.g., Twilley, Dixon, Taylor, & Clark, 1994). Numerous studies have demonstrated the influence of dominance on readers' ability to resolve ambiguities within sentence contexts. When an ambiguous word occurs in a neutral context, in which both meanings are plausible (e.g., "The man knew that the pen . . ."), reading times show that readers are biased to retrieve the more frequent meaning, and show particular difficulty in selecting a meaning for those ambiguous words that have two equally frequent meanings (e.g., Rayner & Duffy, 1986). There are also strong effects of dominance for sentences where the ambiguous word is preceded by a constraining context (e.g., "The man enclosed the livestock with the pen"), such that increases in reading times (relative to an unambiguous base-

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line) only occur when the less frequent (subordinate) meaning is used (e.g., Duffy, Morris, & Rayner, 1988).

Although the importance of meaning dominance is undisputed, very little is known about the nature of these preferences, how they arise and are maintained over time. One possibility is that they reflect a stable property of long-term lexical–semantic representations that develop incrementally over a lifetime's linguistic experience. This view is to some extent implied by the publication of dominance norms (e.g., Twilley et al., 1994), which list the relative frequencies of the different meanings of ambiguous words. These lists are founded on the tacit assumption that meaning preferences for any given word are sufficiently stable (both across and within individuals) that they can be adequately captured by a single value. An alternative view is that our preferences for word meanings are a fluid and flexible aspect of lexical representations that can be strongly influenced by our most recent experience. Despite the vast number of studies that make use of dominance norms, there is, to our knowledge, no experimental data about the extent to which recent experience with an ambiguous word can influence this measure of meaning preference. However, a number of other experimental paradigms have provided evidence consistent with the idea that previous encounters with an ambiguous word in context can affect its subsequent processing.

Experiments that assess changes in reading time between first and subsequent presentations of ambiguous words have provided inconsistent evidence of changes in meaning preference. This may be because the initial dominance of a word's meaning is a critical factor in determining priming. Binder and Morris (1995) have shown that if readers encounter an ambiguous word that has two equally frequent meanings twice within the same passage of text, then gaze durations on the second instance are shorter if the meaning used for the ambiguous word is kept the same, compared with conditions where they had either not previously encountered the ambiguous word or where the alternative meaning of the ambiguous word had been presented. In contrast, Rayner, Pacht, and Duffy (1994; Experiment 2) found no equivalent benefit in reading times for second presentations of a biased ambiguous word where both presentations of the ambiguous word involved the subordinate meaning and were within the same paragraph of text, compared with a condition where the word was not repeated. Thus, single presentations can change meaning preferences for balanced but not for biased ambiguous words. In this latter case, exposure to the subordinate meaning of an ambiguous word is not sufficient to overcome readers' strong tendency to retrieve the word's most frequent meaning.

Although these experiments provide an interesting insight into how processing time changes with repeated presentations of an ambiguous word, the relatively small delay between repetitions, which occurred within the same short paragraph of text, means that we cannot necessarily infer a long-term change in participants' meaning preferences for ambiguous words. This effect may not reflect a change to the lexical–semantic representation that occurs when the ambiguous word is first encountered, but instead may reflect a contextual/semantic priming effect that occurs on the second presentation. Consistent with this alternative explanation, an additional experiment by Rayner et al. (1994; Experiment 1) that used a longer delay between initial exposure and test showed only limited effects of prior exposure. In this experiment, participants learned paired-associates that included eight strongly biased ambiguous words together with words related to their subordinate meaning (e.g., bank-river). In a later part of the experiment, they then read sentences that contained the ambiguous words in subordinate biasing contexts. Initial gaze duration for the critical words (e.g., bank) showed the expected processing disadvantage compared with an unambiguous baseline, and there was no effect of prior exposure. In contrast, the training phase did reduce the probability of regressive eye movements to the critical ambiguous words, suggesting that the repeated exposure may have influenced how easily participants' integrate ambiguous words into on-going discourse.

A second set of relevant studies use a lexical decision task to explore the effect of repeated presentation. A number of studies have shown that for word pairs that include ambiguous words (e.g., "bank-money"), participants were faster to respond to the second word in the pair when they had previously encountered a word pair that used the same meaning of the ambiguous word compared to trials using a different meaning (e.g., responses were faster following "bank-save" than following "bank-stream"). To date, such studies have shown effects that persist across 12 intervening word pairs (Simpson & Kellas, 1989; Simpson & Kang, 1994; Copland, 2006). Similarly, Masson and Freedman (1990) found a robust repetition priming effect for second presentations of ambiguous words preceded by a disambiguating word, only when both presentations used the same meaning (e.g., "piano-organ" primed responses to "music-organ" but not "transplant-organ"). The same effect was observed when, at test, ambiguous words were used as the primes and not as the targets: responses were faster for 'same-meaning' pairs (e.g., "hay-straw" primed "straw-barn") compared with 'different-meaning' pairs (e.g., "hay-straw" followed by "straw-drink"). In all these experiments, however, the critical repeated items were separated by less than a minute of intervening trials. This combined with the use of isolated word pairs makes it difficult to infer changes in meaning preference rather than strategic reactivation of recent decision processes, or priming of recently activated semantic representations.

Finally, Bainbridge, Lewandowsky, and Kirsner (1993) found a similar effect of meaning consistency in an experiment where participants made lexical decisions to ambiguous words that had multiple related senses that were preceded by a biasing sentence context (e.g., "The man kicked the machine after it returned his... TOKEN"). When participants encountered an ambiguous word that they had previously seen, the repetition priming effect was either eliminated or reduced when the biasing sentence frame indicated a different sense of the target word (e.g., "The young widow kept her husband's hair as a...TOKEN"). In this case, the interval between prime and target was somewhat longer as the prime and test items were placed into two separate blocks.

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Thus, although these previous experiments provide evidence that recent experience can change how ambiguous words are responded to in certain tasks, they do not provide a clear answer as to how meaning preferences are biased by their previous encounters with ambiguous words. In addition the relatively short delay between the two instances of the ambiguous word that is typically used in these experiments make it plausible that this effect reflects a form of short-lived semantic priming, whereby the first instance of the ambiguous word acts as a more effective semantic prime in the 'consistent-meaning' condition. Existing demonstrations of 'long-lag' semantic priming such as those published by Becker, Moscovitch, Behrmann, and Joordens (1997) showed semantic priming effects that span a similar number of intervening items and delay between prime and target, without the word repetition seen in the studies that use ambiguous words.

The experiments reported here address the issue of how people's preferences for the different meanings of ambiguous words (as measured by conventional dominance norms) are affected by prior exposure to the ambiguous words during natural sentence comprehension. We use an experimental method that comprises three stages. In an initial priming phase participants make simple semantic relatedness decisions to spoken sentences that contain fully disambiguated ambiguous words. Then, after an unrelated filler task (immediate serial recall for digits), participants perform a word association task similar to that which is typically used to obtain dominance measures for individual words (e.g., Twilley et al., 1994). Critically, this task includes each of the ambiguous words from the sentences presented in isolation. The word associates that participants produce are then coded to assess their preferences for the different meanings of ambiguous words. These scores are compared to the word associate responses from a baseline (unprimed) condition. These experiments use a design commonly found in long term priming studies. However, whereas priming studies usually focus on repetition induced changes in the speed or accuracy of responses in choice RT tasks, we test whether a single presentation of an ambiguous word in a sentence context can influence the preferred meaning for that word presented in isolation. We will refer to any such effect as "word-meaning priming".

Compared with previous studies that have included repeated exposure to an ambiguous word, this method will provide a more direct measure of participants' preferences for the different meanings of an ambiguous word, using the same word-association task that is so prevalent in the literature on ambiguity processing. There are several important characteristics of this method. First, by using isolated words in the test phase (and not complete sentences) we can be certain that any effect of prior exposure reflects a change in how the word itself is processed, rather than a difference in the ease of integrating the meaning of the word into a particular semantic context. Second, the use of a very different task in the two critical phases of the experiments (sentence comprehension vs. word association) will ensure that any priming does not reflect task-specific facilitation but rather a change in meaning preference for these ambiguous words.

Experiment 1

Method

Participants

Sixty native British English speakers who had no reported hearing or reading impairment took part in the study. They were recruited using a University College London online recruiting system and were paid for their participation. One participant was excluded due to poor performance on the vocabulary test. Twenty-nine participants (9 male; mean age = 22.8 years, *SD* = 9.3) were allocated to the unprimed (baseline) condition; and 30 participants (10 male; mean age = 24.2 years, *SD* = 7.7) took part in the primed condition.

Materials

The experimental materials for the priming phase consisted of 59 spoken sentences taken from the stimuli used in a previous fMRI study (Rodd, Davis, & Johnsrude, 2005) and a study of dual task interference (Rodd, Johnsrude, & Davis, 2010). The sentences (mean length = 9.3 words) were spoken by a British English female speaker and each contained two ambiguous words that were disambiguated within the sentence (e.g., "the steak was rare just as the customer has requested"; see Appendix A for full list of sentences). Where possible the subordinate meaning of the ambiguous words was used in order to maximise the potential for increasing participants' preferences for these meanings. However, detailed information about the dominance of these meanings for this population of participants was not available. A conventional measure of dominance will be provided by the unprimed (baseline) condition in this experiment. To obtain a measure of the salience of the ambiguities within the sentences we presented the sentences to a group of 15 participants (who did not take part in the main experiment) and asked them to type in any ambiguous words that they heard. The proportion of participants who successfully reported each of the ambiguous words was used as a measure of its salience. These salience scores were highly variable across items, ranging from 0% to 100% (mean = 68%; *SD* = 23.4). Six additional filler sentences did not contain ambiguities but were otherwise similar to the experimental sentences.

Each sentence was assigned a word probe for use in the relatedness task (see Appendix A for list of probes, see "Design and procedure" for details of the task), as in Rodd et al. (2005). These probes were either highly semantically related (50%; e.g., "The beech and the ash were common in the local forests"…"trees") or unrelated (50%; e.g., "The steak was rare just as the customer had requested"…"floor") to the sentence and were never related to the contextually inappropriate meaning of the ambiguous word. The relatedness task was included to ensure that participants attended to the meaning of the sentence.

The stimuli for the word association task consisted of 118 ambiguous words. These ambiguous words all appeared within the spoken sentences used in the priming phase and were either homonyms (a word that has two or more distinct meanings that are spelt and pronounced

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the same, e.g., "bark") or non-homographic homophones (a word that is spelt differently but has the same pronunciation to another word with a distinct meaning, e.g., "knight/night"). An additional 10 filler words were selected that were not ambiguous but were otherwise similar to the experimental items. Audio files for the ambiguous and filler words were recorded individually by a female speaker of British English (JMR).

The stimuli used in the digit span task comprised 63 randomly-generated number strings (ranging from 3 to 9 digits in length). Finally, a paper version of the adult Mill Hill Vocabulary scale (SET A; Raven, Raven, & Court, 1998) in a multiple-choice format was given to all participants.

Design and procedure

A between subjects design was used in which participants either took part in the unprimed or in the primed condition. All participants were first asked to complete the Mill Hill Vocabulary scale and a language background form in order to assess vocabulary and ensure that participants were native speakers of British English. All subsequent parts of the experiment were presented using E-Prime 1.1 (Schneider, Eschman, & Zuccolotto, 2002) on a computer monitor for the visual word probes and the digit span task, and through headphones for the spoken stimuli. Responses were recorded via a standard keyboard.

Those participants in the primed condition performed three separate experimental tasks: (i) semantic relatedness judgements to auditory sentences (approximately 6 min),[1] (ii) digit span (approximately 8 min), (iii) word association (approximately 18 min). Those participants in the unprimed condition (baseline group) only performed the word association task. During the first task participants were unaware that they would later be performing a word association task and they were not informed that their memory for these sentences would be tested in any way. The three different tasks were presented separately with no indication that stimuli would be repeated across the tasks or that there was any link between the different tasks.

(i) *Semantic relatedness task*. The purpose of this task was to expose the participants to the sentences that contained the ambiguous words and ensure that they attended to the meaning of each sentence. Participants were instructed listen to sentences. At the offset each sentence a fixation cross was replaced with a printed word (i.e., a probe). Participants were asked to respond with a button press to indicate whether this probe was related or unrelated to the sentence meaning. After a 1000 ms inter-trial pause, the next sentence was presented. Each participant completed a short practice block that consisted of six sentence–probe pairs and four lead-in items before hearing the 59 experimental sentences presented in a different randomised order for each participant.

(ii) *Digit span task*. The primary purpose of this test was to provide an additional delay between the priming and test phases of the experiment during which participants were not exposed to any linguistic stimuli that could influence their performance on the subsequent word associate task. In addition it serves as a simple measure of participants' short-term memory capacity. The strings of numbers ranged from 3 to 9 digits and were visually presented one-digit at a time (500 ms per digit). Immediately following the presentation of the digit string, participants were prompted to recall the string using the number keypad on a standard keyboard. There was a 500 ms delay following the participant's response and presentation of the next number string. Participants saw a total of 63 number strings of various lengths in three blocks. A 15-s break was enforced between blocks.

(iii) *Word association task*. The purpose of this task was to measure participants' preferences for the different meanings of the ambiguous words. After each spoken word, participants were prompted to type the word they heard into a textbox that appeared on the screen. This allowed the cases in which the word was misheard to be detected and excluded. On pressing Enter, another textbox appeared and participants were asked to type the first word that came to mind that was related to the word that they had just heard. The next trial began after a 2500 ms pause. The experimental items were presented in a different random order for each participant and were separated into two separate blocks with a short (self-timed) break between blocks. Five filler words were presented at the beginning of each block.

Results

(i) *Vocabulary test*. The mean vocabulary scores were identical for the unprimed group and for the primed group (both 31.1 out of 44; as measured by the Mill Hill Vocabulary test) with no significant difference between these scores ($t_{(57)} = .08$, $p = .9$).

(ii) *Semantic relatedness task*. The performance in this task was good (mean = 94.2% correct, minimum = 79.7% correct) indicating that all participants processed the meaning of the sentences.

(iii) *Digit span task*. Participants' digit span was within the expected range (mean = 7.6 digits, minimum = 6 digits, calculated as the highest length strings for which they achieved at least 50%), indicating that participants were fully engaging with this task.

(iv) *Word association task*.

Main analyses

The responses to five ambiguous words were not included in the analysis: "digit" and "odd" were removed due to concerns that they may be primed by the digit span task; "break" and "brake" were removed because they had both inadvertently been included as ambiguous words, and "company" was removed because its dominant meaning had inadvertently been included as a low-ambiguity word within one of the prime sentences.

[1] This figure is based on the actual times taken by participants to complete the different phases of the experiment, but does not include the short (variable) breaks taken between these different tasks.

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All responses were coded according to whether they were consistent with the meaning used in the sentence from the priming phase or another meaning. For example, the homophone item "knight/night" had appeared in the priming phase within the sentence "the knight began to charge on his horse" and therefore responses such as "knight-castle" and "knight-battle" in the word association task were coded as "consistent" whereas responses such as "night-darkness" were coded as "inconsistent". Responses where the experimental word had been misheard (e.g., "harm" for "palm") were coded as errors. Responses where the associative word could be related to more than one of the meanings were coded as "ambiguous". Errors and ambiguous responses (2.6% of data) were excluded from subsequent analysis.

Proportions of consistent responses were averaged (across items and participants) to generate "consistency" scores, which reflect the proportion of word-associate responses that were consistent with the meaning implied in the sentences, i.e., the relative dominance of the particular meaning that was used in the sentence. The mean consistency score in the unprimed condition was 0.283 ($SD = 0.04$)[2]. This condition provides a measure of baseline dominance for the word meanings used in the sentences, because the participants in this condition had not previously encountered the ambiguous words during the experiment. This score confirms that (on average) the critical word meanings were subordinate. Fig. 1a shows the distribution of these baseline dominance scores across the set of 113 words in more detail. This shows that 55 of the 113 words received unprimed consistency scores (proportion of consistent responses) in the 0–0.2 range indicating that these word meanings were all strongly subordinate. Overall, 74% of word meanings were subordinate in this unprimed condition (consistency scores in the range 0–0.4), 11% of word meanings were balanced (consistency scores in the range 0.4–0.6), and 15% were dominant (consistency scores greater than 0.6).

Compared with these baseline (unprimed) data, consistency scores were significantly higher in the primed condition (0.367 ($SD = 0.07$); $t_{1(57)} = 5.5$, $p < .001$, $d = 1.44$; $t_{2(112)} = 7.8$, $p < .001$, $d = 0.73$; see Fig. 2). This reflects an absolute increase of 8.4% in the consistency scores, or a 29.7% increase in the *proportion* of consistent responses related to the meaning used in the sentences.

Fig. 1b gives an overview of how the strength of the word-meaning priming effect changes as a function of baseline (unprimed) dominance values. Although the absolute magnitude of the priming effects remained relatively consistent for all words with subordinate or balanced meanings as a proportional changes these priming effects are largest for those words with low baseline dominance scores. For example the shift from a baseline dominance of 0.02 to 0.10 reflects a fivefold increase in the likelihood of this meaning being retrieved, whereas the shift from a baseline dominance of 0.43 to 0.51 reflects a much smaller proportional change in likelihood.

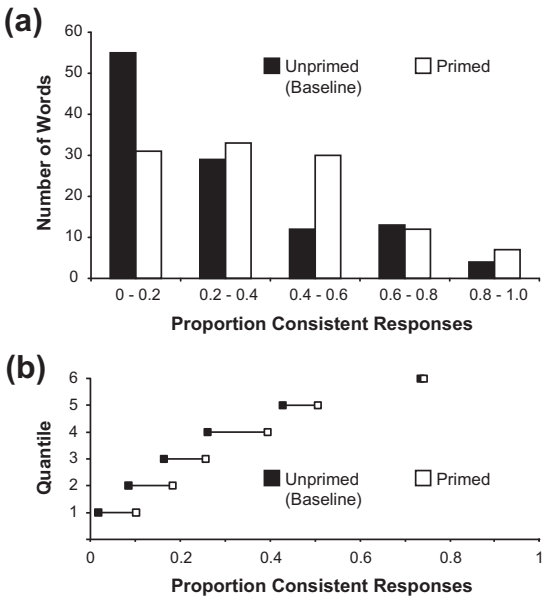

Fig. 1. Experiment 1, word association performance. (a) Distribution of responses across the 113 ambiguous words in the primed and unprimed conditions. The histogram shows the number of ambiguous words for which the proportion of consistent responses was within each of the given ranges. The unprimed results reflect the baseline dominance of the word meanings used in the sentences. The primed results reflect the preference for these meanings when the sentences were previously heard during the meaning relatedness task. (b) The variation of priming as a function of the unprimed (baseline) scores. The 113 items were grouped into six categories (of approximately equal size; $N = 18/19$) on the basis of their unprimed consistency score.

This relationship between baseline dominance and priming was confirmed by an item-wise regression analysis which assessed the factors that influence the magnitude of the change in the likelihoods of the two meanings (quantified by the natural log of the odds ratio of consistent responses for the primed and unprimed groups[3]). This analysis confirmed this measure of priming magnitude was significantly predicted by the overall dominance of the meaning used

[2] Except where stated, all reported standard deviations refer to the subjects analysis.

[3] This measure is suitable for data where the outcome is a dichotomous variable, i.e. each participant's response either is or is not consistent with the meaning of the word that was used in the sentence (see Haddock, Rindskopf, & Shadish, 1998), and the measure expresses the change in the likelihood of the two response categories (consistent/inconsistent) on a numerical scale that is independent of the overall rate of consistent responses. Log odds ratio is calculated as $\ln(p_1/(1-p_1))/(p_2/(1-p_2))$, where p_1 and p_2 are the proportions of sentence-appropriate responses in the exposure and baseline conditions respectively. Following Snodgrass and Corwin (1988), to allow the inclusion of items where no such responses were given, we adjusted these proportions by adding 0.5 to each frequency and dividing by $N + 1$ (where N is the total number of coded responses).

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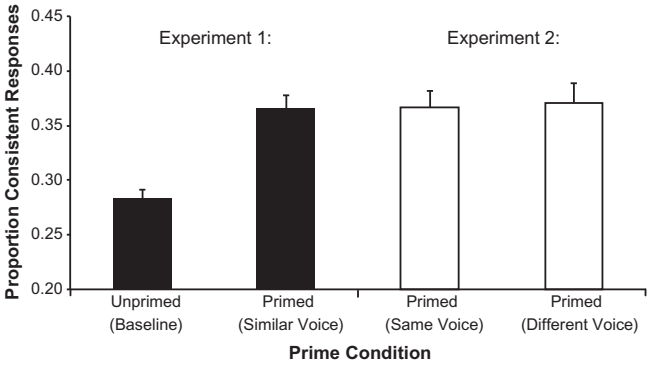

Fig. 2. Experiment 1 and 2, word association performance. Proportion of consistent responses for the different priming conditions. These scores reflect the proportion of responses that were consistent with the meaning used in the prime sentence. Error bars show standard errors adjusted to remove between-subjects variance.

in the prime sentence,[4] with larger priming effects being observed when the sentence meaning was strongly subordinate ($ß = -.82$, $p < .01$). The effects of log-transformed CELEX frequency (Celex; Baayen, Piepenbrock, & Gulikers, 1995) and salience (see "Materials" section) were both non-significant ($ß = -.08$, $p = .17$; $ß = .11$, $p = .7$).

Finally, we did not find any relationship between the priming group's consistency scores and either their vocabulary ($r = .15$, $p = .4$) or their digit span ($r = -.09$, $p = .7$). Thus, within this sample, participants' ability to learn from previous exposure to an ambiguous word was not significantly related to vocabulary size or short-term memory capacity as measured by digit span.

Repeated word analyses

In order to examine the extent to which this observed priming effect may have reflected a tendency for participants to retrieve the specific words that occurred within the relevant prime sentence, we coded each response as to whether the word produced by the participant also occurred within the prime sentence (e.g., steak-rare). Morphological variants of words within the sentence (e.g., plural and past-tense forms) were also classified as a 'repeated word' response. An analysis of these responses showed that these 'repeated word' responses were relatively rare (3% of all responses), but on average they were significantly more frequent in the primed condition compared with the unprimed condition (0.04 ($SD = 0.02$) vs. 0.02 ($SD = 0.02$); $t_{1(57)} = 3.8$, $p < .001$, $d = 0.98$; $t_{2(112)} = 3.6$, $p < .001$, $d = .34$). In addition, we explored whether the priming effect reflected a tendency to retrieve words that were used as the relatedness probe. Again, these responses were relatively rare (2% of all responses), but on average they were significantly more frequent in the primed condition compared with the unprimed condition (0.03 ($SD = 0.03$) vs. 0.006 ($SD = 0.01$); $t_{1(57)} = 4.3$, $p < .001$, $d = 1.12$; $t_{2(112)} = 4.9$, $p < .001$, $d = .46$). Crucially even when these 'repeated word' and 'probe word' responses were excluded from the analysis, the mean consistency scores were significantly higher in the primed condition compared with the unprimed condition (0.29 ($SD = 0.05$) vs. 0.25 ($SD = 0.05$); $t_{1(57)} = 3.2$, $p < .002$, $d = 0.83$; $t_{2(112)} = 3.7$, $p < .001$, $d = .35$).

Discussion

Experiment 1 revealed that a single encounter with an ambiguous word was sufficient to bias listeners' subsequent interpretation of that word after an average delay of 20 min between prime sentence and test presentation. On average, participants who heard the sentences gave 30% more responses that were consistent with the meaning used in these sentences. This shows that the dominance scores that are so prevalent in the ambiguity processing literature are strongly modulated by recent encounters with the target words, particularly for subordinate meanings.

This observed priming effect cannot be entirely attributed to learning of associations between the ambiguous words and other words in a given prime sentence (or the relatedness probe). Although the results did show that there was a proportional increase in word responses that had previously occurred within the prime sentences (or as the relatedness probe), these 'repeated word' responses were relatively rare (5%), and there was also a significant increase in the number of novel, semantically related words that were generated.

One explanation of this priming effect is that it reflects the modulation of abstract lexical–semantic representations such that the meanings that were previously encountered are now more readily available. Such adaptive modulation of the lexical–semantic representations would not only provide a mechanism by which listeners could use their recent experience to enhance current processing, but could also potentially provide a mechanism for accumulating evidence across their lifespan about the relative likelihood of the different meanings. However, an alternative explanation is that the underlying lexical–semantic representations remain unchanged and this priming effect

[4] The overall consistency score averaged across primed and unprimed conditions was used as the measure of dominance. This ensured that this predictor variable was orthogonal to the measure of priming magnitude.

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reflects the influence of participants' episodic representations of the training sentences. Under this view, when participants hear the ambiguous word in the word association task they recall episodic information about the prime sentences and this biases them to retrieve information related to the previously encountered meaning.

In Experiment 2 we contrast these two explanations by assessing whether the strength of priming is modulated by the degree of perceptual overlap between the training and test exemplars. In particular, we ask whether word-meaning priming is observed if the training sentences and test words are not spoken by the same person. Although the training and test items were spoken by two different speakers in Experiment 1, both were female, and had the same regional accent (Southern British English). Informal reports suggested that they were largely indistinguishable. In Experiment 2 the training sentences are presented in one of two voices (male or female) and the word association test was presented in the same female voice allowing a comparison of the degree of word-meaning priming produced by same- and different-voice sentence presentations.

The predictions for this contrast are clear-cut. If the word-meaning priming effect reflects a modulation of abstract lexical–semantic representations then we would not expect the identity of the speaker to play an important role as, according to most models of speech comprehension, this type of perceptual detail is not preserved at a lexical–semantic level of representation. Correspondingly, voice change manipulations do not appear to modulate lexical repetition priming (Luce & Lyons, 1998; Jackson & Morton, 1984). In contrast if the effect reflects a form of episodic learning, whereby responses during the word association task are biased by participants' retrieval of an episodic memory trace of the training sentence, then it is likely that the same-voice condition would provide a stronger retrieval cue. Consistent with this prediction, existing data shows that effects of voice repetition are more pronounced in tests of recognition memory for spoken words (Luce & Lyons, 1998) and that voice-effects on priming are absent in amnesic patients (Schacter & Church, 1995). Evidence of episodic memory involvement would therefore be provided if the meaning-priming effect were larger for ambiguous words presented in the same-voice as during the study phase.

Experiment 2

Method

Participants

Twenty native British English speakers (4 male; mean age = 20.8 years, *SD* = 4.4) who had no reported hearing or reading impairment took part in the study. They were students at University College London (UCL) and were recruited using a UCL online recruiting system and given one course credit for taking part.

Materials

The sentences used during training in Experiment 1 were re-recorded by both a female (JMR) and a male (MHD) speaker. The words used in the test phase were identical to those used in Experiment 1, i.e., spoken by the same female speaker (JMR) as one set of the training sentences.

Design

A within subjects design was used with all participants contributing to both the same- and different-voice conditions. During the priming phase each participant heard a block of sentences spoken by a female speaker and a separate block of sentences spoken by a male speaker. In the test phase the ambiguous words were always presented in the same female voice. Two versions of the experiment were created such that each participant heard each sentence only once but that across participants each sentence was presented in both the same-voice and the different-voice conditions. In addition, two orders of presentation were used such that half the participants in each version heard the same-voice condition first while the other half heard the different-voice condition first. Participants were pseudo-randomly assigned to one presentation of the four combinations of version and order such that five participants took part in each combination of version and order.

Procedure

The overall procedure used was the same as in the experimental condition of Experiment 1 except that during the priming phase the stimuli were divided into two separate blocks which each contained only sentences spoken by one speaker.

Results

(i) *Vocabulary test.* The mean vocabulary score of the participants in this experiment was 28.7 out of 44 (*SD* = 3.5), as measured by the Mill Hill Vocabulary test, which is significantly lower than the mean vocabulary scores of the unprimed group ($t_{(47)} = 2.2$, $p < .05$) and primed group ($t_{(48)} = 2.3$, $p < .05$) of Experiment 1 (both means = 31.1).

(ii) *Semantic relatedness task.* As in Experiment 1, all participants scored highly (mean correct = 95.5%, minimum correct = 87.7%).

(iii) *Digit span task.* Participants' digit span was within expected levels (mean = 7.45 digits, minimum = 6 digits), suggesting that participants were fully engaged with this task.

(iv) *Word association task.*

Main analyses

Responses were coded in the same way as Experiment 1. The results were then analysed in two stages. First, the data from this experiment (combined across condition, version and order) were compared with the data from the unprimed condition in Experiment 1. This analysis confirmed that the consistency scores in this experiment (mean = 0.37, see Fig. 2) showed a significant overall priming effect relative to the consistency scores from the unprimed condition in Experiment 1 (mean = 0.28; $t_{1(47)} = 5.6$, $p < .001$, $d = 1.57$; $t_{2(112)} = 6.6$, $p < .001$, $d = .62$). Similar to the priming group in Experiment 1, participants' consistency scores in this experiment were found to be uncorrelated to vocabulary ($r = -.15$, $p = .5$) or to digit span ($r = -.007$, $p > .9$).

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In the second stage of the analysis, we compared the consistency scores in the same-voice condition (consistency mean = 0.37) and the different-voice condition (consistency mean = 0.38). Analyses of variance (ANOVAs) were conducted, with voice as a within subject variable. Version was included as a dummy variable, but main effects and interactions with version are not reported as they are not central to the issue under investigation (Pollatsek & Well, 1995). The main effect of voice was found to be non-significant: there was no difference between the same voice and the different voice conditions (both $F < 1$).

Repeated word analyses

As in Experiment 1, responses from the word association task were then classified as to whether they occurred either within the corresponding prime sentence or were used as the visual probe word. These 'repeated word' and 'probe word' responses constituted 6.5% of all responses. Once these responses had been removed the data were analysed as in the main analysis. These analyses showed the same pattern of results as the main analysis: consistency scores in this experiment (mean = 0.33) showed significant priming relative to the unprimed condition from Experiment 1 (mean = 0.25; $t_{1(47)} = 5.1$, $p < .001$, $d = 1.46$; $t_{2(112)} = 2.1$, $p < .05$, $d = 0.2$), but there was no significant difference the consistency scores in the same-voice condition (mean = 0.33) and the different-voice condition (mean = 0.33; both $F < 1$).

Discussion

The results from Experiment 2 show that word-meaning priming is not significantly modulated by a change in the speaker's voice between the prime sentence and test word: priming for words spoken in a female voice was of a similar magnitude regardless of whether the prime sentences had been heard in the same female voice or in a different male voice. In conjunction with the finding from Experiment 1 that word-meaning priming remains reliable when responses from the original sentence are excluded this suggests that recall of episodic memories of the prime sentences is not the primary mechanism underlying word-meaning priming.

Two alternative explanations of the word-meaning priming effect remain. First, it is possible that each encounter with an ambiguous word produces a change to participant's stored information about the relatively likelihoods of its different meanings, such that the listener now has an increased preference for the recently encountered meaning. For example, after hearing the sentence "The star had many fans who came to all his concerts", participants preference for the "supporter" meaning of the word "fan" may increase relative to their preference for the "cooling device" meaning. The alternative explanation is that this word-meaning priming effect reflects a non-specific form of semantic priming, such that the recent encounter with this sentence has enhanced processing of any subsequent information that is semantically related to the topic of the sentence. This would be directly analogous to a conventional semantic priming task in which a single encounter with the prime word "doctor" produces facilitation of subsequent processing of semantically related words such as "nurse" (Collins & Loftus, 1975). Under this semantic priming account, participants are not learning about the ambiguous word itself, but instead their increased preference for one of its meanings reflects priming of all semantic representations related to the meaning of the sentence that they previously encountered.

The considerable delay between priming and test (more than 20 min) in Experiment 1 makes the latter explanation somewhat unlikely – there are few demonstrations of semantic priming effects that span multiple intervening items, let alone an extended period including an engaging distractor task and a change of task between prime and target processing. Even those effects referred to in the literature as 'long-term semantic priming' use a considerably shorter delay between the prime and its corresponding target than was used in the current experiments. For example, Becker et al. (1997) used a design in which there was a 2 min pause between the blocks of prime items and target items, and the longest average lag between prime and targets in their experiments was 21.5 items. However because no previous studies have assessed long-term semantic priming using a word association measure we cannot completely rule out the possibility that the current word-meaning priming effects might reflect a general semantic priming effect.

In Experiment 3 we will directly address this issue by comparing the extent to which the word-meaning priming effect is contingent on the presence of the critical ambiguous words within the prime sentences. We will compare the effectiveness of prime sentences which do contain the target ambiguous word (e.g., "The footballers were greeted warmly by the adoring *fans*") to matched sentences with highly similar meanings that do not contain the ambiguous word (e.g., "The footballers were greeted warmly by the adoring *supporters*"). If the word-meaning priming effect reflects specific learning about the relatively likelihoods of the ambiguous word's meaning then priming should only be observed when the ambiguous word itself is present in the prime sentence. In contrast, if word-meaning priming reflects a more general form of semantic priming then both types of sentences should be able to prime the "supporter" meaning of the word "fan" on the subsequent word association test.

As well as comparing these two types of sentence primes, Experiment 3 will also explore the time course of both general semantic priming and of word-meaning priming. The experiment will measure the magnitude of priming when the delay between prime and target is either 3 or 20 min. Based on previous studies of semantic priming Becker et al. (1997), we expect to see semantic priming to be evident at the shorter 3-min delay, but not at 20 min. In contrast, based on the results of Experiment 1 we expect to see significant word-meaning priming after both short and longer delays.

Experiment 3

Method

Participants

Forty-two native British English speakers (10 male; mean age = 22.3 years) with no reported hearing or reading

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impairments took part in the study. They were students at University College London (UCL) and were recruited using a UCL online recruiting system and given either one course credit or £6 for taking part. Participants were pseudorandomly assigned to each of the six versions such that an equal number of participants took part in each version.

Materials

The sentences used in the priming phases of the experiment consisted of 54 newly developed pairs of word-meaning and semantic prime sentences (mean length = 11.9 words). The word-meaning primes each contained an ambiguous word that was disambiguated towards its subordinate meaning (e.g., "The man accepted the post in the accountancy firm"; see Appendix B for the sentences). The ambiguous words were either non-homographic homophones (e.g., "prophet/profit") or homonyms (e.g., "deck"). The subordinate meaning was selected on the basis of dominance norms (Gawlick-Grendell & Woltz, 1994; Nelson, McEvoy, Walling, & Wheeler, 1980; Sereno, Pacht, & Rayner, 1992; Twilley et al., 1994). The corresponding semantic prime sentences were identical except that the ambiguous word was replaced with a low-ambiguity word with essentially the same meaning in that context (e.g., "The man accepted the job in the accountancy firm").

In order to create the six versions of the experiment (see "Design and procedure"), the 54 pairs of sentences were divided into six sets of nine sentences. Each version of the experiment contained one of these sets in each of the six conditions, counterbalanced across versions such that each set only occurred in a particular condition in one version of the experiment. Eighteen additional low-ambiguity filler sentences with similar properties were included to distract from the ambiguity. Eleven low-ambiguity sentences with similar properties were used in the practice block and as lead-in items at the start of the experimental block. All spoken materials in this experiment were spoken by the same female speaker of British English (JMR).

The word probes to be used in the semantic relatedness task were the same for both sentences within each pair, and were always semantically unrelated to the sentence meaning and thus to the meaning of the target ambiguous word. This eliminated the possibility that any observed priming effects could be attributable to participants purely remembering associated word probes (see Experiment 1 "Results"). The probes assigned to the low-ambiguity filler sentences were all strongly related to the sentence meaning, giving an overall relatedness proportion of 33%. One-third of probes assigned to the practice sentences were semantically related to the sentence meaning.

The stimuli for the digit span task were the same as in Experiment 1.

Pretest

A pre-test was conducted to ensure that the meaning of the semantic primes were sufficiently similar to the word-meaning primes. Seventeen native British English speakers (3 males, age 22–28) were recruited via social networking sites to complete the online pre-test using Survey Monkey questionnaire software (http://www.surveymonkey.com). They were not rewarded for their participation. The pre-test included 81 potential semantic prime sentences that were presented alongside the ambiguous word that was to be used in the corresponding word-meaning prime sentence with the critical words in capital letters (e.g., "The second LAYER of paint went on more easily than the first" – "COAT"). Participants were instructed to rate the extent to which the meaning of each sentence would change if the word in the sentence in capital letters was replaced by the word next to it. The rating scale ranged from 1 to 7, with 1 being 'completely changed' 4 being 'slightly changed' and 7 being 'completely unchanged'.

Sixty filler sentences were included together with words that were plausible within the sentence context, but which would change the meaning of the sentence either moderately ($N = 30$; e.g., "The young girl was told that the RABBIT was very timid" – "ANIMAL") or substantially ($N = 30$; e.g., "They were certain that the FARM would be sold quickly" – "APARTMENT"). These fillers were included to encourage participants to use the full extent of the rating scale and to confirm that each participant was following the instructions. The order of the sentences was randomised for each participant. Two example sentences with ratings were given at the beginning of the pre-test. There was no time limit.

The data from one participant was removed because they rated a large number of the filler sentences as being 'completely unchanged', indicating that they were not following the instructions. Results from the filler sentences indicated that the remaining participants were performing the task correctly. The 'moderate change' fillers were rated as having changed less than the 'substantial change' fillers (mean scores = 3.48 vs. 1.74). Only sentences with a rating of 5.0 or above were included in the main experiment. Out of the 81 original sentences, 54 met this criterion.

Design and procedure

A crossed within-subject, between-item and between-subject, within-item design was used. The two independent variables were the priming condition (word-meaning priming, semantic priming and unprimed) and the length of delay between prime and test phases (short and long). Six versions of the experiment were created such that each participant only encountered each ambiguous word in one of the six experimental conditions, but that across participants, each ambiguous word occurred equally in each of the six conditions.

As in Experiments 1 and 2, there were three different tasks: semantic relatedness (priming phase), digit span (filler task) and word association (test phase). In order to measure participants' meaning preferences for the ambiguous words at both a short (3 min) and long (20 min) delay between prime and test, participants completed each of the three tasks twice in the order presented in Table 1. Participants heard a total of 27 sentences (nine word-meaning priming, nine semantic priming and nine unambiguous filler) in each of the two semantic relatedness tasks. Participants heard a total of 27 ambiguous words in each of the word association tasks. A practice block of nine sentences was completed before participants heard the sentences in the first semantic relatedness task. One lead in sentence was completed at the beginning of each semantic related-

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Table 1
The order of tasks in Experiment 3. The durations (in min and s) are based on the actual time participants spent on each of the tasks and do not include the time between each task in which participants read short instructions about the next task.

Task	Average duration (min s)	Average study to test delay (min s)
1. Semantic relatedness (long delay)	3.04	
2. Digit span	5.06	
3. Semantic relatedness (short delay)	2.57	
4. Word association (short delay)	3.14	3.06
5. Digit span	4.44	
6. Word association (long delay)	3.30	19.18

ness task. One lead in word was presented at the beginning of each word association task. All other aspects of the timings and instructions procedure were the same as in Experiment 1.

Results

(i) *Semantic relatedness task.* All participants performed this task accurately (mean correct = 95.9%; minimum correct = 89.3%), indicating that that they processed the meanings of the sentences.

(ii) *Digit span task.* Participants' digit spans were in the expected range (mean = 7.4 digits, minimum 5 digits) indicating that subjects were engaged with this task.

(iii) *Word association task.*

Main analyses

All responses were coded in the same way as Experiment 1. Errors and ambiguous responses (1.4% of the data) were removed as in Experiment 1. One ambiguous word ("hay") was removed from the analysis because its mean consistency score across all conditions was 0.97 indicating that the strongly dominant meaning had inadvertently been used.

The mean consistency scores for each of the six experimental conditions (Fig. 3a) were entered into repeated measures ANOVAs separately assessing the significance of word-meaning priming (word-meaning primed vs. unprimed), semantic priming (semantic primed vs. unprimed) with Delay as a second factor. We then compared word-meaning and semantic priming directly in a further analysis. In each of these Anovas version was included as a dummy variable with six levels, but main effects and interactions involving this factor are not reported (cf. Pollatsek & Well, 1995).

(i) *Word-meaning priming vs. unprimed.* The mean consistency scores were significantly higher in the word-meaning priming conditions compared with the unprimed conditions ($F_{1(1,36)} = 23.0$, $p < .001$, $\eta_p^2 = .39$; $F_{2(1,47)} = 13.7$, $p < .001$, $\eta_p^2 = .23$). The main effect of Delay was not significant (both $p > .4$), nor was the interaction between Priming and Delay (both $p > .2$), indicating that the word-meaning priming effect was not significantly modulated by delay. To confirm the specific predictions that word-meaning priming should be significant at both delays, separate ANOVAs were then conducted at each delay with Priming and Version as factors.

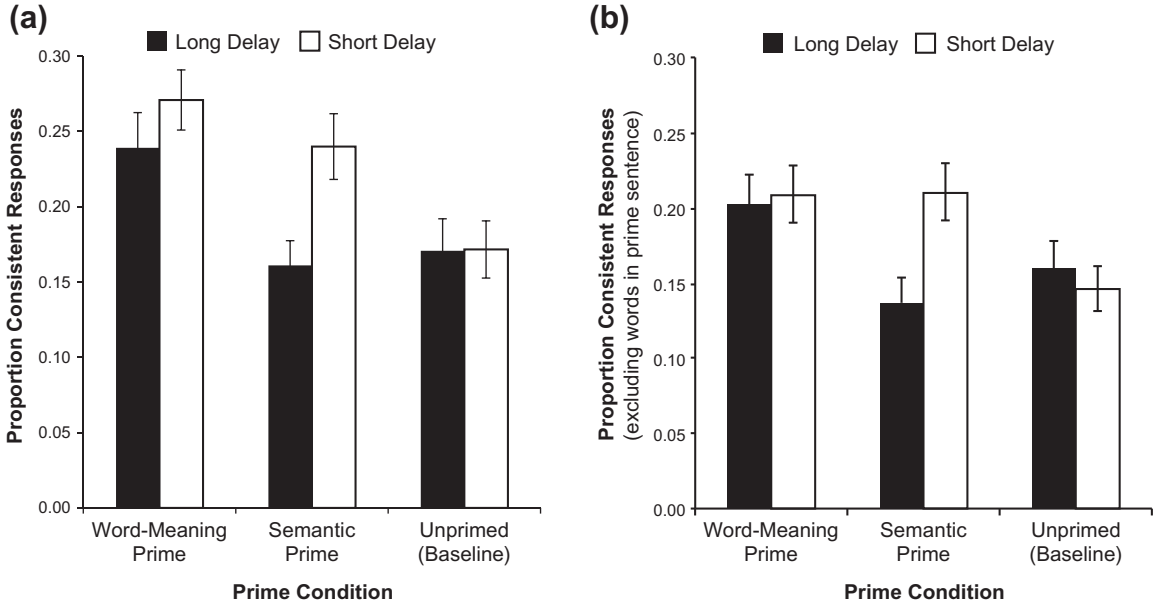

Fig. 3. Experiment 3, word association performance. Proportion of consistent responses for the three priming conditions at the two delays (short: 3 min, long: 20 min). Error bars show standard errors adjusted to remove between-subjects variance.(a) Main analysis. (b) Repeated word analysis: All responses that correspond to a word within the prime sentence were excluded.

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These confirmed that there was significant priming after both the long delay ($F_{1(1,36)} = 4.8$, $p < .05$, $\eta_p^2 = .12$; $F_{2(1,47)} = 5.6$, $p < .05$, $\eta_p^2 = .11$) and the short delay ($F_{1(1,36)} = 15.9$, $p < .001$, $\eta_p^2 = .31$; $F_{2(1,47)} = 11.1$, $p < .01$, $\eta_p^2 = .19$).

(ii) *Semantic priming vs. unprimed*. The mean consistency scores were higher in the semantic priming conditions compared with the unprimed conditions, but this effect was only marginally significant ($F_{1(1,36)} = 3.1$, $p = .09$, $\eta_p^2 = .08$; $F_{2(1,47)} = 3.9$, $p = .05$, $\eta_p^2 = .08$). The main effect of Delay was only significant by items ($F_{1(1,36)} = 2.8$, $p = .1$, $\eta_p^2 = .07$; $F_{2(1,47)} = 4.8$, $p < .05$, $\eta_p^2 = .08$). Importantly there was a significant interaction between these two variables ($F_{1(1,36)} = 5.0$, $p < .05$, $\eta_p^2 = .12$; $F_{2(1,47)} = 5.7$, $p < .05$, $\eta_p^2 = .12$), indicating that the priming effect was significantly larger after the short delay than after the long delay. Separate ANOVAs which included only priming and version as factors confirmed that the priming effect was significant after the short delay ($F_{1(1,36)} = 7.4$, $p < .01$, $\eta_p^2 = .17$; $F_{2(1,47)} = 9.8$, $p < .01$, $\eta_p^2 = .17$) but not after the long delay (both $p > .4$).

(iii) *Word-meaning priming vs. semantic priming*. The mean consistency scores were significantly higher in the word-meaning priming conditions compared with the semantic priming conditions ($F_{1(1,36)} = 9.3$, $p < .01$, $\eta_p^2 = .21$; $F_{2(1,47)} = 7.6$, $p < .01$, $\eta_p^2 = .14$). Consistency scores were also significantly higher after a short delay compared with the long delay ($F_{1(1,36)} = 5.2$, $p < .05$, $\eta_p^2 = .13$; $F_{2(1,47)} = 9.2$, $p < .01$, $\eta_p^2 = .16$). The interaction between these variables was not significant (both $p > .2$). Separate ANOVAs which included only Priming and Version as factors showed that the difference between the lexical and semantic priming conditions was significant after the long delay ($F_{1(1,36)} = 10.2$, $p < .01$, $\eta_p^2 = .22$; $F_{2(1,47)} = 10.1$, $p < .01$, $\eta_p^2 = .18$) but not after the short delay (both $p > .2$).

Repeated word analyses

Responses from the word association task were classified as to whether they occurred within the corresponding prime sentence in order to investigate the extent to which the priming effects were solely due to participants retrieving words that were contained within the sentence primes via associative priming between the ambiguous word and other words that co-occurred within the prime sentence (see Experiment 1). Responses that corresponded to the words that were only included in the semantic prime sentences were not removed because these never co-occurred with the ambiguous word. These 'repeated word' responses constituted 3.9% of all responses. Removing these responses reduced the overall proportion of consistent responses, but the overall pattern of responses in the six conditions remained very similar to that seen in the main analysis (Fig. 3b). The same repeated-measures ANOVAs described above were conducted to confirm that word-meaning priming remains distinct from semantic priming when responses containing words from the priming sentences are excluded.

As before, mean consistency scores were significantly higher in the word-meaning priming conditions compared with the unprimed conditions ($F_{1(1,36)} = 7.5.0$, $p < .001$, $\eta_p^2 = .17$; $F_{2(1,47)} = 8.5$, $p < .01$, $\eta_p^2 = .15$). The main effect of Delay was not significant (both $p > .8$), nor was the interaction between Priming and Delay (both $p > .2$), indicating that word-meaning priming is of similar magnitude at short and long delays. The separate ANOVAs conducted at each delay with Priming and Version as factors showed that priming was not significant after the long delay ($F_{1(1,36)} = 1.8$, $p = .19$, $\eta_p^2 = .05$; $F_{2(1,47)} = 2.7$, $p = .1$, $\eta_p^2 = .05$) but was significant after the short delay ($F_{1(1,36)} = 6.2$, $p < .05$, $\eta_p^2 = .15$; $F_{2(1,47)} = 7.1$, $p < .01$, $\eta_p^2 = .13$). The absence of a significant priming effect at the long delay is somewhat surprising given the numerical difference between these conditions (see fig. 3) and the significant effect for this comparison in the main analysis above, but in the absence of a significant interaction between delay and condition, this null effect should be treated with caution.

The mean consistency scores were numerically higher in the semantic priming conditions compared with the unprimed conditions, but this effect was not significant (both $p > .1$). The main effect of Delay was also not significant (both $p > .1$). However, there was a significant interaction between these two variables ($F_{1(1,36)} = 5.8$, $p < .05$, $\eta_p^2 = .14$; $F_{2(1,47)} = 5.4$, $p < .05$, $\eta_p^2 = .10$), suggesting (as before) that the magnitude of semantic priming was larger after the short delay compared with the long delay. ANOVAs which included only priming and version as factors confirmed that the priming effect was significant after the short delay ($F_{1(1,36)} = 5.3$, $p < .05$, $\eta_p^2 = .13$; $F_{2(1,47)} = 7.0$, $p < .05$, $\eta_p^2 = .13$) but not after the long delay (both $p > .3$).

Finally, we compared consistency scores in the word-meaning and semantic priming conditions. The effect of priming condition was only significant in the items analysis ($F_{1(1,36)} = 2.3$, $p = .14$, $\eta_p^2 = .06$; $F_{2(1,47)} = 5.2$, $p < .05$, $\eta_p^2 = .10$), as was the effect of delay (greater priming at short delays; $F_{1(1,36)} = 2.9$, $p = .1$, $\eta_p^2 = .08$; $F_{2(1,47)} = 5.3$, $p < .05$, $\eta_p^2 = .10$). The interaction between priming condition and delay was significant in the subjects but not the items analysis ($F_{1(1,36} = 4.3$, $p < .05$, $\eta_p^2 = .11$; $F_{2(1,47)} = 1.1$, $p > .2$). While this pattern of results is somewhat at odds with the previous analysis, separate ANOVAs once more confirm that the difference between the word-meaning and semantic priming conditions was significant after the long delay ($F_{1(1,36)} = 6.1$, $p < .05$, $\eta_p^2 = .15$; $F_{2(1,47)} = 7.4$, $p < .01$, $\eta_p^2 = .14$) but not after the short delay (both $p > .4$). Taken together, these analyses indicate that the critical aspects of these results remain robust when these repeated words have been removed.

General discussion

Taken together the results of these experiments demonstrate that a single encounter with a particular meaning of

an ambiguous word in context is sufficient to bias a listener's interpretation of that word after a delay of up to 20 min. On average, the proportion of responses that were consistent with the previously encountered meaning increased by 30% (Experiments 1 and 2) or 40% (Experiment 3) compared to unprimed baseline conditions. This word-meaning priming effect indicates that the dominance scores that are so prevalent in the ambiguity processing literature are strongly influenced by participants' recent encounters with the target words, and indicates that our most recent experience with an ambiguous word plays an important role in determining how it is currently interpreted. Given the ubiquity of results in the literature showing how ease of disambiguation is strongly influenced by the dominance of a word (e.g., Duffy et al., 1988), we suggest that this ability to use recent experience to guide disambiguation is likely to be an important factor in making listeners so efficient at dealing with ambiguities in natural conversation: once a listener has encountered a meaning of an ambiguous word once in a conversation subsequent disambiguation will be made easier by this apparent shift in meaning preference.

Experiment 1 showed that the magnitude of this word-meaning priming effect is modulated by the baseline dominance of the ambiguous word's meaning. Although the absolute magnitude of the priming effects remained relatively stable for words with subordinate or balanced meanings (see Fig. 1b), as a proportional changes these priming effects are largest for those words with low baseline (unprimed) dominance scores. For example the shift from a baseline dominance of 0.02 to 0.10 reflects a fivefold increase in the likelihood of this meaning being retrieved. This relationship between baseline dominance and priming was confirmed by an item-wise regression analysis which showed that sentence exposure had a larger influence on relative meaning likelihoods of words with strongly subordinate meanings.

Experiment 3 showed that this word-meaning priming effect was not strongly modulated by delay. Although there was a numerical difference between the effect of word-meaning priming when the average delay between prime and target was 3 min (58%) compared with 20 min (40%), the interaction between Priming and Delay was not significant. The magnitude of the word-meaning priming effect at 20 min in this experiment (40%) was somewhat larger than was seen in Experiment 1 (30%). This most likely reflects a difference in the baseline dominance scores for the two sets of stimuli, such that the proportion of subordinate meanings was higher for Experiment 3 (average unprimed dominance of 17%) compared with Experiment 1 (average unprimed dominance of 28%).

The results of Experiments 1 and 3 also indicate that word-meaning priming is unlikely to be contingent on explicit awareness of the ambiguity at the time of priming. In Experiment 1, the effect was not significantly predicted by the likelihood that participants would notice each ambiguous word within its sentence context (as measured by a pretest using a different group of participants). In addition, the word-meaning priming effect was not attenuated in Experiment 3 in which the proportion of sentences that contained an ambiguous word during the priming phase was reduced to 33% in order to reduce the salience of the ambiguous nature of the sentences. Taken together these two findings suggest that explicit awareness of the ambiguous words is unlikely to be a critical factor in the word-meaning priming effect.

Our preferred explanation of this effect is that it arises from a long term change in the degree to which the form of an ambiguous word is associated with a particular meaning. However, before concluding that we have seen a change in form-to-meaning links we must first rule out some alternative explanations. We believe that the results should not be attributed to a simple form of associative or episodic learning between each ambiguous word and other words in its prime sentence. Although the results of these experiments indicated that there was a proportional increase in word responses that had previously occurred either within the prime sentences or as the relatedness probe, it is important to note that the presence of these 'repeated words', which are often strong associates of the ambiguous words, should not be taken as evidence that episodic factors are *necessarily* involved. For example, following the prime sentence "Bark is found on the trunk of many trees", several participants produced the response "tree" to the ambiguous word "bark", but this response was also present (to a lesser extent) in the unprimed condition, and so it is possible that the likelihood of this response increased in the primed condition due to a general increase in the availability of the primed meaning of the ambiguous word "bark" and not because the word "tree" was present in the training sentence. More importantly, both experiments showed a significant main effect of word-meaning priming even when these responses were removed. These results indicate that there was a significant increase in the number of novel, semantically related words that were generated. For example, after hearing the training sentence "The prophet/profit had a staff in his hand", participants in the primed condition of Experiment 1 gave many words associated with "prophet" that are unrelated to participants' episodic memory for the sentence (e.g., "religion", "Jesus", "Moses", "disciple", "messiah", "preach").

A further piece of evidence that is contra to the predictions of an episodic memory account is that Experiment 2 showed that the word-meaning priming effect is equally robust under conditions in which there is a clear change in speaker between the priming and test phases. This again suggests that the effect is not modulated by a factor (voice congruency) that is known to modulate episodic memory tests such as recognition memory for spoken words (e.g., Luce & Lyons, 1998), but not lexical priming (Luce & Lyons, 1998; Orfanidou, Davis, Ford, & Marslen-Wilson, 2011). Taken together, these arguments suggest that the word-meaning priming effect is unlikely to be entirely episodic in nature or to be based on recently learned associations between ambiguous words and the sentences in which they were recently heard.

A second alternative explanation of the word-meaning priming effect is that it results from a form of purely semantic priming. Under this view, a listener would prefer a particular meaning of the ambiguous word because they had recently encountered congruent semantic information, regardless of whether they had recently encountered the ambiguous word itself. This account is ruled out by the re-

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sults of Experiment 3 which compared the priming that was produced by pairs of sentences which were rated as having highly similar meanings and which differed only in whether or not the ambiguous word itself was present. In contrast to the robust effects of word-meaning priming, effects of semantic priming were overall weaker, and interacted significantly with delay, such that there was a significant increase in the proportion of consistent responses produced after 3 min (40%) but no increase compared to baseline preferences after 20 min. Critically, at the 20 min delay there was a significant difference between the semantic priming condition and the word-meaning priming condition (even when the 'repeated words' had been removed). This pattern of results is consistent with the prevailing view in the literature that semantic priming is a relatively short-lived phenomenon and suggests that current theories of semantic priming (e.g., spreading activation models, compound cue models; see Jones (2010) for a recent review) are unlikely to provide an appropriate framework in which to explain the word-meaning priming effect, which remains robust after a delay of 20 min.

This finding that word-meaning priming is contingent on the repeated presentation of the same ambiguous word in both the prime sentence and as a target word suggests that this word-meaning priming paradigm is more closely allied to repetition priming effects, which are known to be long lasting (e.g. lasting a year in studies of picture naming; Cave, 1997). Interestingly, studies using pictures indicate that long-term repetition priming effects may often depend on close overlap between the tasks performed during study and test (Vriezen, Moscovitch, & Bellos, 1995; Horner & Henson, 2009). However, while the present experiments use very different tasks during the study phase (sentence comprehension) and the test phase (word association), it could be argued that just as 'standard' long-term repetition priming paradigms reflect an improvement in participants ability to map from the input stimulus to an output response, the current study reflects an improvement in their ability to map from the input (wordform) stimulus to the semantic representation that was appropriate in the prime sentence.

More specifically, we suggest that as a consequence of the initial encounter with the ambiguous words, listeners strengthen the association between a word's form (phonological for our experiments since they used spoken presentation) and the representation of the meaning that was accessed during sentence comprehension. This explanation is consistent with distributed connectionist models of how ambiguous words are recognised (Rodd, Gaskell, & Marslen-Wilson, 2004; Kawamoto, Farrar, & Kello, 1994; Joordens & Besner, 1994). These models characterise word recognition as a process by which distributed representations of word forms are mapped onto distributed representations of meaning (semantics). For example, in the Rodd et al. (2004) model, which was primarily concerned with modelling data from single word recognition tasks (Rodd et al., 2002; Rodd, 2004), when the form of an ambiguous word is encountered, this activation feeds forward to activate the semantic units that are associated with its meanings. Initially, this pattern of semantic activation corresponds to a blend (or mixture) of its two meanings, but the recurrent connections between the individual semantic units then 'clean up' this activation to ensure that the network settles into a pattern of activation that corresponds to one of its known meanings. Within this framework, any recent experience with one of the meanings would strengthen the connections between its form-based and semantic representations such that when the model next encounters the word's form there is an increased probability of it settling into the recently encountered meaning.

This explanation of the word-meaning priming effect is closely related to the account put forward by Binder and Morris (1995) to explain their finding that gaze durations on the second instance of an ambiguous word are shorter if the meaning used for the ambiguous word is kept the same. They interpreted their results within the reordered-access model of ambiguity resolution (Duffy et al., 1988) in which all meanings of an ambiguous word are accessed, but the relative order with which they become active is influenced by both the relative dominance of the meaning and by the context in which the word occurs. Binder and Morris (1995) suggest that their results are best accounted for by assuming that a prior encounter with an ambiguous word can boost the availability of the meaning that was selected. However, while this account is similar to the connectionist account described above in that it emphasises the increased availability of the previously encountered meaning, these account diverge in their predictions for the situation where two different meanings of an ambiguous word are encountered in turn. According to the reordered-access model (Duffy et al., 1988) an encounter with an ambiguous word in context should have *no* consequence for the meaning that was not selected (see Binder and Morris (1995) for detailed discussion). In contrast, the distributed connectionist model put forward by Rodd et al. (2004) predicts that the strengthening of the mapping to one of a word's meaning should necessarily come at the expense of reducing the availability of the alternative meaning, and so a prior encounter with the alternative meaning of a word should interfere with its current processing. Future work is clearly needed to resolve this issue. Although some studies have suggested that there is *no* disadvantage for retrieving a previously inappropriate meaning of an ambiguous word relative to a baseline condition in which the ambiguous word has not previously been encountered (Binder & Morris, 1995), it is difficult to rule out the possibility that the interfering effect of switching meaning may be masked by form-based facilitation that arises from repeated presentations of the word's form.

An additional prediction that arises from the distributed connectionist account of these data (Rodd et al., 2004) is that the phenomenon of word-meaning priming may not be restricted to ambiguous words. This account predicts that, even for low-ambiguity words, each time that word is encountered within a sentence context the links between its word form and meaning will be strengthened. However it seems likely that the impact of word–meaning priming for low-ambiguity words may be reduced relative to high-ambiguity words due to their simpler form-to-meaning mapping (Rodd et al., 2004). In addition, any word-meaning priming effects for low-ambiguity words will usually be confounded by phonological (or orthographic) repetition priming effects, which are usually attributed to facilitation

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in the processing of a word's phonological/orthographic form (Luce & Lyons, 1998; Orfanidou et al., 2011).

This facilitation of the mapping between word-form and word-meaning that is driven by sentence level disambiguation is directly analogous to the lexically-driven retuning of phoneme representations shown in studies of perceptual learning of speech (Norris, McQueen, & Cutler, 2003). In this work, presentation of an ambiguous phoneme (e.g., a fricative midway between /s/ and /f/) in lexically-constrained contexts (such as at the offset of words like *beef* or *peace*), produces a lasting change to participants' interpretations of ambiguous /s/–/f/ segments presented in isolation. Whereas top-down interactions between lexical and phonemic processing during online processing remain controversial (Norris, McQueen, & Cutler, 2000; McClelland, Mirman, & Holt, 2006), all are agreed that long-term learning can only be plausibly explained by a form of top-down, lexically-driven perceptual retuning (see Davis, Johnsrude, Hervais-Adelman, Taylor, and McGettigan (2005) and McQueen, Norris, and Cutler (2006) for further discussion and related evidence). We note that this parallel between lexical/semantic and phonemic ambiguity resolution is consistent with arguments made by Mirman and colleagues (Mirman, 2008; Mirman, McClelland, & Holt, 2006).

There is also a useful parallel to be drawn between these results and the finding reported by Monsell and Hirsh (1998) that response times increase for a monosyllabic word (e.g., "bran") when it is preceded by a word that shares its onset and vowel (e.g., "brag"). This effect was seen with lags of more than 5 min between prime and probe and was also found for similar pairs of polysyllabic words that share their first syllable (e.g., "beacon-beaker"). This 'competitive priming' effect is only seen when both the prime and targets are real words. The authors suggest that "successful recognition of a word makes that same word easier to recognise on the next encounter, at least for several minutes, but at the cost of making similar words harder to recognize". Our data suggest that not only are listeners biased to interpret perceptually ambiguous input (e.g., "bra…", "beak…") as consistent with their previous lexical experience, they also tend to interpret semantically ambiguous words in line with previous experience of sentences containing those words.

Since we have shown similar long-term changes in participants' interpretations of ambiguous spoken words, we argue that our data contribute to the increasingly compelling body of evidence showing retuning of speech processing representations on the basis of recent experience. At both the semantic and phonological levels, we see clear evidence of a role for top-down learning processes that support speech comprehension. Listeners dynamically adjust perceptual and lexical processes to better accommodate phonologically and semantically ambiguous speech. We suggest that these data reflect a learning mechanism that operates not only to maintain the relevant lexical/semantic representations during natural comprehension, but may also directly contribute to the development of long-term knowledge about the likelihood of any given meaning. This view is consistent with functional considerations concerning the role of priming mechanisms in supporting lexical knowledge, and with the claim that "priming is a behavioural manifestation of learning processes embedded with perceptual (and sometimes conceptual) systems whose main function is to identify (or interpret) perceptual inputs" (Bowers & Kouider, 2003).

In addition, this view of a speech comprehension system in which every encounter with a word's form and its meaning results in a strengthening of the connection between these two representations has a direct parallel within the word production literature. In a model put forward to account for semantic interference effects in word production (i.e., slower naming of a picture of "dog" following naming of the semantically related picture "cat"), Oppenheim, Dell, and Schwartz (2010) suggest that every time a word is produced there is a strengthening of the connections between the word's semantic features and its lexical representation and that this enhancement of the processing of a recently produced word necessarily comes at a cost for other words that share (input) semantic features.

Several unanswered questions about word-meaning priming remain. First, it is not yet certain that this effect reflects the early stages of listeners' long-term learning about word meanings. Future studies using a longer delay (days or weeks) between training and test are needed to reveal the time-course of this effect and to characterise how listeners integrate their recent and distant experiences with words and their meanings. Of clear relevance here is recent evidence about the time-course of lexical consolidation, which suggests that new information is only consolidated into the lexicon over a longer time-scale than in the current experiment, and that sleep may play a critical role in this process (see Davis and Gaskell (2010) for review). The evidence used to support this view of lexical consolidation comes primarily from studies in which participants are required to learn the phonological forms of lexical items that are entirely new to them. However, we have recently shown that competition from recently learned meanings similarly involves an extended period of learning (Rodd et al., 2012). This contrasts with the short-term re-tuning of previously established lexical representations explored here. It will be for future studies to determine whether or not short-term and longer-term retuning involves the same learning process. Future studies are also needed to determine whether this form of learning occurs whenever an ambiguous word is encountered within a sentence context, or whether it only occurs under more specific circumstances. One possibility is that the word-meaning priming effect is specifically triggered whenever an ambiguous word is initially misunderstood such that the sentence must be reinterpreted. An alternative possibility is that this form of retuning is most efficient when the appropriate meaning is rapidly retrieved with little interference from the inappropriate meaning.

It is also important to note that the results of Experiment 2, which found no effect of a change in the identity of the speaker on the magnitude of priming, do not rule out the possibility that it may be possible, under some circumstances, to learn this type of information in a way that is specific to an individual speaker. It is plausible, for example, that a benefit for a "same-voice" condition might emerge for speakers that are personally known or highly familiar to the listener, or in a situation in which the two

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speakers concerned come from different linguistic communities. For example, exposure to a second-language speaker, or to someone with a strong regional accent, might not produce a change in lexical/semantic representations that generalises to a native speaker of one's own dialect.

Finally, while this method provides valuable insights into the effect of repeated presentation on a commonly used measure of meaning preference (word-association norms), there is a clear need for future studies examine the impact of such word-meaning priming on online comprehension. Previous reading time experiments that have looked at the effect of repeated exposure to ambiguous words suggest that the relationship between word-meaning priming and online comprehension may be far from straightforward, particularly with respect to the effects of baseline dominance: while the current studies have suggested that word-meaning priming has a particularly strong effect for strongly subordinate meanings, studies of reading appear to show the reverse effect, i.e., significant effects of repeated exposure for balanced but not subordinate meanings (Binder & Morris, 1995; Rayner et al., 1994). These findings suggest that the change in relative preferences for the strongly subordinate meanings seen using the current word-meaning priming method may not be sufficient to overturn the long-term preference for the alternative, dominant meaning and thereby prevent this meaning from being preferentially accessed (e.g., Duffy et al., 1988). In other words, while exposure to a strongly subordinate meaning may result in a fivefold increase its dominance score (e.g., from 0.02 to 0.10) readers would still be highly likely to retrieve the dominant meaning and so a single encounter with an ambiguous words would not be sufficient to overturn the subordinate bias effect. Future studies are clearly needed to confirm more precisely how the changes in meaning preference that are revealed by word-meaning priming effects translate into changes during online comprehension of these words at both the relatively short delays that were used in the reading time studies (Binder & Morris, 1995; Rayner et al., 1994), and at the longer delays (20 min) that were used in the current experiments.

In summary, the work presented here provides a method by which we can observe how listeners learn about the relative likelihoods of word meanings. The reliable impact of a single training episode suggests that the sorts of dominance measures that are routinely used in psycholinguistic studies of ambiguity resolution should not be viewed as stable, static properties of lexical representation, but instead as highly fluid, flexible characteristics that are continually updated in order to optimise the efficiency of comprehension. This form of lexical–semantic retuning, like other demonstrations of phonological retuning in speech perception, demonstrates a key role for rapid, online adaptation in human speech comprehension.

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Appendix A

Sentence materials and relatedness probes for semantic relatedness task (Experiments 1–2). Ambiguous words are underlined. The dominance scores refer to the baseline (unprimed) consistency scores for the two underlined ambiguous words. From Experiment 1 and reflect the proportion of participants who gave an associate that was related to the meaning used in the corresponding sentence.

Sentence	Probe type	Probe	Dominance word 1	Dominance word 2
A bug was used to tap the apartment	Related	secret	0.04	0.00
A spade was not the suit that the card player wanted	Related	unlucky	0.07	0.03
Bark is found on the trunk of many trees	Related	branch	0.48	0.22
She missed the company of her friends	Related	alone	0.18	
The ball was organised by the pupils to celebrate the end of term	Related	enjoy	0.24	0.38
The beech and the ash were common in the local forests	Related	trees	0.03	0.14
The blind on the window kept out the sun	Related	shade	0.18	0.96
The board tried to prevent the strike	Related	union	0.07	0.19
The change was meant as a tip for the waitresses	Related	coins	0.29	0.31
The knight began to charge on his horse	Related	combat	0.07	0.41
The peace was broken when more arms were delivered	Related	weapon	0.82	0.07
The poll suggested that the party would lose the election	Related	survey	0.11	0.00
The ring was still in its case when they left the jewellers	Related	bought	0.76	0.72
The shell was fired towards the tank	Related	battle	0.00	0.00

(continued on next page)

Appendix A (*continued*)

Sentence	Probe type	Probe	Dominance word 1	Dominance word 2
There was a mole on his temple just below his hairline	Related	dinner	0.32	0.18
They kept a record of the events in the log	Related	report	0.14	0.10
A pen was used by the farmer to enclose the stock before he moved them to the market	Related	cattle	0.07	0.14
Bulbs are normally sold during the spring	Related	garden	0.31	0.57
He walked from the dock to the cell at the end of the trial	Related	prison	0.00	0.15
His calf was only strained and would heal quickly	Related	muscle	0.32	0.76
It was free for juniors to join the club	Related	youth	0.11	0.38
The cast learned their cues that afternoon	Related	actress	0.38	0.14
The coach started to brake too late	Related	speed	0.86	
The creak came from a beam in the ceiling	Related	attic	0.52	0.52
The head of the local branch was replaced when the company was reorganized	Related	manager	0.11	0.00
The pitch of the note was extremely high	Related	music	0.32	0.24
The punch was served in a large pitcher	Related	drink	0.07	0.21
The seal came up onto the bank of the river	Related	shore	0.52	0.00
The star had many fans who came to all his concerts	Related	famous	0.00	0.34
A bar was used to smash the pane of glass	Unrelated	pencil	0.14	0.10
He searched the deck for the ace of diamonds	Unrelated	tragic	0.17	0.71
His new post was in China	Unrelated	equal	0.07	0.69
It was the weak that suffered when the new ruler came to power	Unrelated	arrange	0.72	0.17
The cymbals were making a racket	Unrelated	catch	0.28	0.17
The flour was added to the sauce	Unrelated	costume	0.03	0.82
The match ended as a tie	Unrelated	climate	0.24	0.04
The panel were supposed to ignore the race and sex of the contestants	Unrelated	trench	0.48	0.04
The port was used for the toast at the end of the banquet	Unrelated	green	0.39	0.04
The prophet had a staff in his hand	Unrelated	estate	0.21	0.21
The sentence was decided by the court	Unrelated	Alarm	0.10	0.50
The weight was too much for the scales	Unrelated	Allow	0.45	0.72
There were currants in the roll	Unrelated	tower	0.10	0.39
There were dates and pears in the fruit bowl	Unrelated	circus	0.14	0.56
A band was sewn onto the hat	Unrelated	height	0.07	0.66
He was lying underneath the palm on the beach	Unrelated	apple	0.15	0.30
His presents arrived in the mail	Unrelated	talent	0.61	0.41
She filed her nails before she polished them	Unrelated	police	0.10	0.37
She saw a hare while she was skipping across the field	Unrelated	subject	0.07	0.72
The break given to the guards between their watches was very short	Unrelated	cottage		0.00
The cabinet was surprisingly light and easy to carry	Unrelated	early	0.79	0.07
The craft left a wake behind it	Unrelated	tactic	0.17	0.07
The letters and the digits were the identical size	Unrelated	candle	0.22	
The lock on the chest had been broken with the poker	Unrelated	style	0.31	0.17
The opening chord was drowned out by the bass guitar	Unrelated	paper	0.24	0.15
The plot of the story was extremely odd and difficult to follow	Unrelated	voice	0.21	
The principal decided that the boarders should all return home	Unrelated	string	0.39	0.00
The steak was rare just as the customer had requested	Unrelated	floor	0.79	0.21
The waist of the jeans was very narrow	Unrelated	amuse	0.28	0.48
The was thyme and sage in the stuffing	Unrelated	study	0.07	0.71

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Appendix B

The 54 word-meaning prime and semantic prime sentences used in the semantic relatedness task (Experiment 3). The first underlined word in each sentence is the ambiguous word that was contained in the word-meaning prime sentence and the second underlined word is the semantically related word that was contained in the semantic prime sentence. All probes for the experimental items were semantically unrelated. The dominance scores refer to the baseline (unprimed) consistency scores from Experiment 3 for the ambiguous word and reflect the proportion of participants who gave an associate that was related to the meaning used in the corresponding sentence.

Sentence	Probe	Dominance
The man accepted the post/job in the accountancy firm	hat	0.00
The footballers were greeted warmly by the adoring fans/supporters	menu	0.14
The bowl of alcoholic fruit punch/drink at the party was most definitely spiked	truck	0.00
The second coat/layer of paint went on more easily than the first	baby	0.14
She used glue to stick/secure her photograph onto the application form	student	0.21
The poll/survey revealed that the majority of people were going to vote for the Labour party	badminton	0.07
The football coach/instructor they had chosen had a lot of experience	apartment	0.00
The town planner did not want to use that plot/area of land for housing	toilet	0.36
The editor was surprised to find a passage/section of text that had not yet been translated	lion	0.29
The deck/pack of cards he chose had been shuffled very well	nanny	0.14
The lawyer presented a very strong case/argument to the jury	zoo	0.23
The spring/coil under the bed broke because they jumped too hard	spider	0.21
The farmer explained that the pen/enclosure was mainly used for the livestock	lap	0.00
The policemen were impressed with the boy's courageous deed/act	annoyed	0.61
The student lost the cap/lid that went with her favourite biro	strong	0.00
The figure/shape of the girl was perfect for the dress	music	0.57
The ruler/leader of the country was very popular indeed	printer	0.15
They bowed down in front of the stone idol/statue and started to pray	biscuit	0.21
The cab driver was stuck in the traffic jam/stationary traffic for a very long time	fish	0.07
The secretary had to keep a log/record of every telephone call she made to each client	psalm	0.24
The children were excited for bedtime when their mother would finish reading the tale/story	supervisor	0.23
The boy chose one kitten from the litter/group of six that were still with their mother	warehouse	0.07
The bible told the story of the prophet/messenger sent by god	stadium	0.14
The journey to the airport was very long so they stayed in the inn/tavern overnight	hockey	0.29
The cast/plaster on his leg was fitted by an experienced doctor	keyboard	0.58
The student who won the poetry competition clearly had a certain flair/talent for writing	illness	0.07
The postman tried to deliver the mail/letters on time	magic	0.50

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Appendix B (*continued*)

Sentence	Probe	Dominance
The cleaner was annoyed to find the cat's paw/foot prints all over the kitchen floor	skirt	0.07
They looked out of the window and saw the lightning bolt/strike hit the tree	baseball	0.14
The seamstress couldn't find the reel/spool of cotton she was looking for	summer	0.00
The other driver did not see her coming so she pressed the horn/hooter immediately	addition	0.43
She had to wring/squeeze out the water from the clothes because the washing machine broke	french	0.00
She bugged/pestered her brother to give her the present early	calculator	0.07
The business man worked his way up the firm/company very quickly	shallow	0.08
She was terrified when she felt herself sinking/falling further into the quicksand	knife	0.29
The military complained that they did not have enough arms/weapons to fight the war	television	0.23
They learnt about the cycle/sequence of the seasons in nursery	newspaper	0.00
The school children were terrified of being hit with the belt/strap	lamppost	0.07
The addict hid his stash of crack/cocaine from the police	kangaroo	0.14
The shop keeper drew/pulled out a gun from beneath the counter in self defence	airport	0.00
He won the comedy competition for the best gag/joke	treasure	0.29
I watched her skate across the ice with effortless grace/elegance	factory	0.29
The students found the three hour examination very hard/challenging	gossip	0.07
They all got high/stoned at the party last weekend	tie	0.14
She tried to explain that it was just/simply a mistake	song	0.07
She was so proud to see her daughter in the school's end of year Shakespeare play/performance	model	0.29
The stalk/stem of the plant seemed to be very sturdy	dna	0.36
The tip/advice the student was given for the exam was really helpful	bank	0.00
The athlete had to train/exercise a lot in preparation for the marathon	sheep	0.07
Everyone said that he looked very trim/slim after dieting	brake	0.07
Eventually she found the perfect dress for the school ball/dance	mole	0.00
Every morning the farmer took fresh hay/straw out to the barn	soldier	
They were so excited to see the King's royal throne/chair which looked magnificent	campaign	0.29
The students picked their essay title from a wide range/variety of topics	hat	0.14

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