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How meaning similarity influences ambiguous word processing: the current state of the literature

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Abstract

The majority of words in the English language do not correspond to a single meaning, but rather correspond to two or more unrelated meanings (i.e., are homonyms) or multiple related senses (i.e., are polysemes). It has been proposed that the different types of "semantically-ambiguous words" (i.e., words with more than one meaning) are processed and represented differently in the human mind. Several review papers and books have been written on the subject of semantic ambiguity (e.g., Adriaens, Small, Cottrell, & Tanenhaus, 1988; Burgess & Simpson, 1988; Degani & Tokowicz, 2010; Gorfein, 1989, 2001; Simpson, 1984). However, several more recent studies (e.g., Klein & Murphy, 2001; Klepousniotou, 2002; Klepousniotou & Baum, 2007; Rodd, Gaskell, & Marslen-Wilson, 2002) have investigated the role of the semantic similarity between the multiple meanings of ambiguous words on processing and representation, whereas this was not the emphasis of previous reviews of the literature. In this review, we focus on the current state of the semantic ambiguity literature that examines how *different types* of ambiguous words influence processing and representation. We analyze the consistent and inconsistent findings reported in the literature and how factors such as semantic similarity, meaning/sense frequency, task, timing, and modality affect ambiguous word processing. We discuss the findings with respect to recent parallel distributed processing (PDP) models of ambiguity processing (Armstrong & Plaut, 2008, 2011; Rodd, Gaskell, & Marslen-Wilson, 2004). Finally, we discuss how experience/instance-based models (e.g., Hintzman, 1986; Reichle & Perfetti, 2003) can inform a comprehensive understanding of semantic ambiguity resolution.

Keywords

Language comprehension; Semantics; Ambiguity; Polysemy; Homonymy

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In many languages, a large portion of words are semantically ambiguous in that a single word form captures multiple senses or meanings. Given this, it is not surprising that scientists have spent decades trying to understand how semantic ambiguity is resolved, and how semantically ambiguous words are processed.

Early work in this area focused on whether or not both meanings of an ambiguous word were activated, and how biasing context, meaning frequency, and contextual strength influenced meaning activation (e.g., Adriaens et al., 1988; Duffy, Kambe, & Rayner, 2001; Gorfein, 1989, 2001; Hogaboam & Perfetti, 1975; Martin, Vu, Kellas & Metcalf, 1999; Onifer & Swinney, 1981; Simpson, 1981, 1994; Vu, Kellas, & Paul, 1998). Past research (e.g., Duffy, Morris & Rayner, 1988; Vu et al., 1998) has demonstrated that the presence versus absence of context, meaning frequency, and contextual strength interact during lexical ambiguity resolution.

More recent research in this area has emphasized how the semantic similarity between the meanings and senses of ambiguous words affects representation and processing. The present review will focus on more recent studies and models that examine the semantic similarity between ambiguous word meanings and senses. Prior studies demonstrated, albeit inconsistently, an advantage for ambiguous words in lexical decision tasks (Azuma & Van Orden, 1997; Borowsky & Masson, 1996; Hino & Lupker, 1996), and a disadvantage for ambiguous words in tasks that required specification of meaning (e.g., Hino, Lupker, & Pexman, 2002). Despite this body of work, there is still debate about precisely how semantic ambiguity is resolved. Importantly, previous research did not always distinguish between the various types of semantically ambiguous words. Here, we focus on a distinction based on the semantic similarity of ambiguous word meanings. For example, homonyms are words that have a single orthographic form but two or more unrelated meanings (e.g., “bank”). Polysemes, on the other hand, are semantically ambiguous words that also share a single orthographic form, but have multiple related senses (e.g., research/wrapping “paper”). Critically, the majority of ambiguous words are polysemous rather than homonymous (e.g., Klein & Murphy, 2001). In this review, we refer to *senses* as the multiple instantiations of polysemous words, and to *meanings* as the multiple instantiations of homonymous words.

Polysemous words can be distinguished from each other based on the source of ambiguity. For example, *metonymous polysemy* occurs when the interpretations of both senses of a polysemous word are literal, and these senses are connected in meaning through one of various types of relationships. For example, the polysemous word “chicken” has a count/mass (countable/uncountable) distinction that refers to the animal and the meat of that animal. Other forms of metonyms include container/contents (e.g., holding a “glass” of orange juice vs. drinking a “glass” of orange juice), synecdoche, in which the part of something represents the whole (e.g., “wheels” representing part of vs. the whole car), and figure/ground (e.g., “cage”: the structure vs. the enclosed space). These aforementioned forms of polysemous words are considered *regular* polysemes because the relationships between the varying senses are formed via predictable relationships (e.g., container/contents, mass/count). Some polysemous words have less predictable connections between the different senses; these are referred to as *irregular* polysemes. For example, *metaphorical polysemy* occurs when one sense of a polysemous word has a more literal interpretation

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and the other has a more figurative interpretation. The word "eye", for example, refers to a body part and to part of a storm. In general, the senses of metonymous polysemes are similar to each other in meaning and are connected via literal relationships, whereas the senses of metaphorical polysemes are less related in meaning because their relationships are less concrete. Regular polysemous senses may be easier to process because the connections and relationships are more concrete.

From a linguistic perspective, a set of rules based on the relationship between the different meanings/senses of an ambiguous word can be used to categorize it as polysemous or homonymous (e.g., Pustejovsky, 1995). From a psychological perspective, the way that word definitions are categorized in the dictionary can be used to define ambiguity (e.g., Klein & Murphy, 2001; Rodd et al., 2002), such that words with two separate dictionary entries are classified as homonyms, whereas words with multiple definitions that are listed under the same entry are classified as polysemes. The dictionary classification approach has also been used to determine meaning frequency/dominance such that the earlier-listed definitions correspond to the more frequent interpretations. By contrast, other researchers have used norms to classify ambiguous words into subtypes. In this method, participants come up with associations for each word and then semantic similarity ratings are collected by a second set of participants to determine how related in meaning the different associations that correspond to various meanings/senses are to each other (e.g., Hino et al., 2002; Pexman, Hino, & Lupker, 2004).

Although it is practical in experimental design and consistent with theories of ambiguity to classify ambiguous words in a categorical fashion, ambiguous words can be aligned along a continuum of semantic similarity of the multiple meanings/senses (Klepousniotou, 2002; Klepousniotou & Baum, 2007; Klepousniotou, Pike, Steinhauer, & Gracco, 2012; Klepousniotou, Titone, & Romero, 2008). Additionally, more recent advances in statistical analysis make it possible to analyze the data using continuous variables. Homonyms would be at one end of the continuum, metonymous polysemes would be on the other end, and metaphorical polysemes would be in the middle.

Recent studies on ambiguous word processing and representation have taken into consideration the different types of semantically ambiguous words and the level of semantic similarity of the ambiguous words' meanings (e.g., Armstrong & Plaut, 2008; Klepousniotou, 2002; Rodd et al., 2002). Some researchers have found that polysemous words with more related senses have an *advantag*e in lexical decision tasks, such that polysemous words are responded to faster than unambiguous words, whereas homonyms have a small *disadvantage* in a lexical decision task such that homonyms are responded to more slowly than polysemous and unambiguous words (Beretta, Fiorentino, & Poeppel, 2005; Rodd et al., 2002). Other studies have demonstrated a processing *disadvantage* for homonyms during tasks that are more semantically engaging such as the semantic categorization task (Hino et al., 2002). However, mixed results have been found (Hino, Kusunose, & Lupker, 2010; Hino, Pexman, & Lupker, 2006), and the causes of these processing advantages and disadvantages are still debated. The present review will focus on these recent studies of semantic ambiguity effects and will highlight potential reasons for the inconsistent results reported in the literature.

Study selection criterion

Because there are several review articles (e.g., Simpson, 1984) and books (e.g., Adriaens et al., 1988; Gorfein, 1989, 2001) about semantic and lexical ambiguity that were published prior to 2001, we have chosen to focus on behavioral and electrophysiological studies on semantic ambiguity published between 2001 and the present. Studies included in this review were located using Google Scholar and PsychINFO using the following search terms: homonymy, polysemy, semantic ambiguity, and lexical ambiguity. Further, because we focus on the similarities and differences between different types of ambiguous words, we will include detailed summaries only of studies that specifically examined different types of ambiguous words (e.g., polysemes and homonyms).

Review outline

This review will explore the consistent and inconsistent patterns across studies. First, we will discuss aspects of semantic ambiguity processing and representation and will then review the recent behavioral and electrophysiological research on semantic ambiguity (see Table 1 for a summary of reviewed studies). To foreshadow, the results of recent studies have reported several inconsistent ambiguity effects. We will discuss factors that may contribute to the inconsistent results found in the literature, including the types of words used in each study, the semantic similarity of the word meanings, the type of response on critical trials (e.g., yes vs. no), the type of task, the modality (auditory, visual), timing, and the type of foils (e.g., pronounceable non-words vs. pseudohomophones) used. To aid in our review, Table 1 outlines these factors for each experiment reviewed. We will discuss how these factors contribute to the overall level of semantic activation in the entire language network (e.g., as determined by tasks that do vs. do not emphasize semantics) and the semantic activation of semantically ambiguous words' specific meanings/senses, which may lead to these varying results and effects reported in the literature. Finally, in the discussion sections, we will consider how these literatures have contributed to our understanding of models of semantic ambiguity and examine how parallel distributed processing (PDP) and experience-based models can inform a better understanding of semantic ambiguity resolution.

Overview of models of semantic ambiguity

Researchers have framed ambiguity effects with respect to storage and lexical access. Both polysemous and homonymous words correspond to multiple senses or meanings. These ambiguous word types differ in terms of the semantic relationships between the multiple senses or meanings. There are two alternative frameworks for how polysemes and homonyms are represented. The first is the Separate Entry Model (e.g., Langacker, 1987), which proposes that, because each ambiguous word has meanings/senses that vary in relatedness along a continuum, each meaning or sense is stored separately in the mental lexicon and is tied to a single orthographic/phonological form. This situation would apply for both polysemous and homonymous words. The second alternative is grounded in the theoretical linguistic perspective (e.g., Nunberg, 1979) of polysemous words and is referred to as the Single Entry Model. Under this view, when words have highly related senses (as do polysemes), the senses are stored together. However, when the meanings of an ambiguous word are unrelated, each meaning is stored separately in the mental lexicon. There are two different specific instantiations of the Single Entry Model of polysemous words. One alternative is that the different senses share a "core meaning" and each sense is generated by a set of relationships or rules (Nunberg, 1979). The second alternative is that the representations of the multiple senses are underspecified and the distinct senses are derived online (e.g., Pustejovsky, 1995). Although there is less consensus regarding how polysemous words are represented, the majority of researchers agree that the multiple meanings of homonyms are stored separately in the mental lexicon and assert that homonym meanings are distinct and only accidentally to map to the same word form (Klein & Murphy, 2001; Klepousniotou et al., 2012; Srinivasan & Snedeker, 2011). These theoretical models have provided a way to understand and predict how homonyms and polysemous words are represented and processed in the mind. However, these models do not take into consideration important factors such as varying degrees of semantic similarity or meaning/sense frequency.

Several researchers have used computational models such as those from the PDP tradition to examine ambiguity representation and processing (e.g., Armstrong & Plaut, 2011; Hino et al., 2002; Rodd et al., 2004). Computational models have the advantage of including semantic and orthographic information and testing specific hypotheses about how the mind organizes and represents different types of ambiguous words. Additionally, PDP models can provide a single mechanistic account of how different types of words are processed and represented. In PDP models, each layer is made up of nodes or units, which represent features of a word such as orthography, phonology, or the meaning. For ambiguous words, each orthographic pattern corresponds to more than one semantic pattern, whereas for unambiguous words each orthographic pattern corresponds to just one semantic pattern. Modelers can train the network to learn the one-to-one and one-to-many mappings from orthography to semantics and test how quickly and accurately the model responds to different types of words. After training, the model will "settle" to the nadir of energy, known as an attractor basin. Attractor basins are points of attraction that are shaped by the strength of the connections between the nodes. For example, a shallow attractor basin could correspond to a core meaning or features shared by the multiple senses of polysemous words. This parallels the Single Entry View, according to which polyseme senses are stored together in the mental lexicon. A deep attractor basin could represent a specific meaning that corresponds to a meaning of an ambiguous or unambiguous word. This parallels the Separate Entry View, according to which homonym and/or polyseme meanings/senses are stored separately.

In the following review of the literature, we will examine two issues. The first issue is how ambiguous words and their meanings are represented in the mental lexicon. The second is how ambiguous words are processed. Although the different issues address ambiguity effects from a representational versus processing standpoint, similar methodologies can be used to examine them. For example, comparisons of lexical decisions to polysemous, homonymous, and unambiguous words have been used to infer both the ease with which participants process the different types of words (e.g., Armstrong & Plaut, 2011; Klepousniotou & Baum, 2007), and how those words are represented in the mind (e.g., Beretta et al., 2005). In the next section, we review recent *behavioral* studies of semantic ambiguity, beginning with less semantically engaging tasks such as lexical decision, followed by more semantically engaging tasks such as semantic judgments.

Review of behavioral studies

Less semantically engaging tasks

In this section, we will discuss experiments that used tasks such as lexical decision, which do not necessarily require the specific semantic code of the word to be activated to accurately make a response. Rather, accurate responding in this task can be accomplished with the recognition of the orthographic or phonological form as a word.

Previous studies using lexical decision have shown that ambiguous words tended to yield faster response times than unambiguous words (e.g., Azuma & Van Orden, 1997; Pexman & Lupker, 1999). However, that early work may not have distinguished between polysemes and homonyms, thus semantic similarity between the meanings/senses was not well controlled. The first few studies to disentangle these two forms of ambiguity were conducted by Klepousniotou (2002) and Rodd et al. (2002). Across three lexical decision experiments, Rodd et al. examined how multiple related and unrelated senses and meanings of semantically ambiguous words influenced processing. In Experiment 1, words with more senses were responded to more quickly than words with fewer senses, and words with many meanings were responded to more slowly than words with few meanings. In Experiment 2, a factorial design was implemented in which comparisons were made between words with many senses and few meanings, few senses and many meanings, many senses and many meanings, and many senses and few meanings. As in Experiment 1, words with many senses were responded to more quickly than words with few senses. Further, homonyms elicited slower RTs than words with few meanings in the participant analysis, but this difference was not statistically significant. Importantly, both experiments included pseudohomophones (e.g., “brane”) as non-words because previous studies that employed this type of non-word (rather than non-pseudohomophone word-like non-words; e.g., “lork”) had reported significant ambiguity effects (Azuma & Van Orden, 1997). This may be because pseudohomophones make it more difficult to distinguish between non-words and real words. Thus, making a lexical decision may require more activation of the word’s meaning(s)/senses. This may lead to greater ambiguity effects because the multiple meanings/senses will be activated, therefore impacting the processing of those words.

Interestingly, in Experiment 3, Rodd et al. (2002) found a similar pattern of results as in Experiment 1 (an advantage for words with many senses and a disadvantage for words with many meanings) using an auditory lexical decision task. Because it was an auditory task, Rodd et al. (2002) could not use pseudohomophones and therefore used pronounceable non-words instead. This finding is somewhat surprising given that Azuma and Van Orden (1997) found ambiguity effects in visual lexical decision only when using pseudohomophones as non-words. This result goes against the idea that difficult non-words are needed in lexical decision to affect the activation of the multiple meanings/senses. However, because auditory lexical decisions are slower in general, it may be that the additional time in processing allowed the multiple meanings/senses to be sufficiently activated to affect processing.

In sum, the Rodd et al. (2002) study demonstrated that the previously reported ambiguity advantage (e.g., Pexman & Lupker, 1999) was not due to a general ambiguity advantage but rather that this advantage may be limited to polysemous words. It had been hypothesized that the previously reported ambiguity advantage was due to ambiguous words having richer semantic representations than unambiguous words. However, if the ambiguity advantage is limited to polysemous words, then it may be that related senses facilitate recognition, whereas unrelated meanings inhibit recognition.

As stated previously, polysemous words can be divided into different types based on the regularity and semantic similarity of the multiple senses. In a study that went beyond the the number of senses/meanings classification used by Rodd et al. (2002), Klepousniotou and Baum (2007) compared performance for different types of polysemes. Specifically, they tested metaphorical and metonymous polysemes, and examined the effects of type of ambiguity and meaning/sense dominance on auditory and visual lexical decision task performance. In Experiment 1, Klepousniotou and Baum used an auditory lexical decision task and found that metaphorical and metonymous polysemes elicited faster response times than balanced and unbalanced homonyms and unambiguous control words. In Experiment 2, they used a visual lexical decision task and found an advantage for metonymous polysemes over metaphorical polysemes, homonyms, and unambiguous words. These results provide further support for a polysemy advantage in processing, and possibly to a special status for metonymous polysemes, which may have senses that are more related to each other than do other types of polysemes. Klepousniotou and Baum did not observe a homonym disadvantage, suggesting that the polysemy advantage for metonymous polysemes may be more robust than the homonym disadvantage. The data from Experiment 2 also demonstrated that not all polysemes benefit from an advantage in processing, because metaphorical polysemes yielded similar RTs to the homonyms and unambiguous words. This may be because metaphorical polyseme senses are less related than those of metonymous polysemes. Therefore, it is important to examine meaning similarity effects in ambiguity processing at a finer-grained level than classifying all polysemous words under the same category (see also McElree, Frisson, & Pickering, 2006, for evidence regarding further possible distinctions between logical and standard metonyms).

It is important to note that Klepousniotou and Baum (2007) used the same materials in both the auditory and visual lexical decision experiments. Previous studies that found different results in auditory and lexical decision had used different non-words in the two modalities, namely pronounceable non-words in the auditory lexical decision task and pseudohomophones in the visual lexical decision task. In Klepousniotou and Baum's study, differences between the visual and auditory tasks cannot be due to the differences in non-words because they were the same in both tasks. Different results might, however, be due to the speed with which participants recognized the words in each modality; the RTs were faster overall in the visual lexical decision task than the auditory task, which may have influenced semantic activation levels of the words' meanings/senses. Specifically, both types of polysemes were responded to faster than the other word types in the auditory task, but the responses were slower overall, which may have allowed the semantic activation of the metaphorical polysemous word senses to reach a level of activation that facilitated word recognition. Because lexical decisions were faster in the visual task, it is possible that the semantic activation of the words' senses did not reach a level sufficient to speed lexical decision for the metaphorical polysemes, but was strong enough to do so for the metonymous polysemes (see Armstrong, 2012, and Discussion: Processing Issues below, for discussion of how the time course of semantic activation of the words meanings/senses influences ambiguity processing).

However, not every study has found a disadvantage or null effects for homonyms. Lin and Ahrens (2010) examined ambiguity effects in a Mandarin lexical decision study. The ambiguous words in their study were homonyms or metaphorical polysemes, but did not include ambiguous words with more related senses such as metonymous polysemes. Their non-word stimuli were pseudohomophones. Lin and Ahrens found an ambiguity advantage in RT such that the ambiguous words were responded to faster than the unambiguous words overall; they did not distinguish results for the two types of ambiguous words. These results contradict the notion that an ambiguity advantage is found only for polysemes with highly related senses. Importantly, including pseudohomophones as non-words is hypothesized to increase overall semantic activation at the whole language network level (i.e., emphasize semantic processing). These results contradict that prediction and provide counter-evidence to the relatedness of meaning advantages in lexical decision tasks. However, because Lin and Ahrens did not compare the two types of ambiguous words in their stimulus set, and because they did not include other types of polysemes such as metonyms, it cannot be determined whether metonymous or metaphorical polysemes in a similar task would have a processing advantage above and beyond that of the homonyms and unambiguous words.

Additionally, using a Japanese lexical decision task with Katakana words as non-words, Hino et al. (2006, Experiment 1) did not find evidence for a specific polysemy advantage. Rather, they reported an overall ambiguity advantage in which polysemes and homonyms were responded to more quickly than unambiguous words. Further, there were no differences between RTs to polysemes and homonyms. These findings are also inconsistent with the view that there is no homonym advantage.

To further investigate these inconsistencies, Hino et al. (2010) specifically investigated an ambiguity advantage that was restricted to polysemes that had been reported in previous lexical decision studies, but that their research group had not previously found. In Experiment 1, Hino et al. (2010) used Katakana Japanese words and non-words and found an overall ambiguity advantage in reaction time, but no differences between polysemous and homonymous words. As discussed above, previous studies had found an ambiguity advantage only when using pseudohomophones, which are thought to increase semantic processing (Azuma & Van Orden, 1997; but see above discussion of Rodd et al., 2002, Experiment 3). Katakana non-words cannot be made into pseudohomophones but, because Japanese Kanji characters are morphemes, Hino et al. proposed that adding Kanji characters to their stimulus list may increase semantic processing, thus simulating a stimulus list similar to the one used by Rodd et al. (2002). Indeed, after adding Kanji characters as non-words and words (Experiment 2), Hino et al. found a polysemy advantage, such that polysemes were responded to more quickly than homonyms and unambiguous words, with no differences between the latter two types of words.

However, Hino et al. (2010) noted that the Kanji characters may have induced strategic changes rather than increasing overall semantic activation. The Kanji non-words in the experiment contained characters that were unrelated (i.e., the two characters that made up a single non-word were unrelated to each other), whereas the Kanji words contained characters that were related to each other. This manipulation therefore may have provided a cue to participants about the correct response, altering their decision-making strategy. Thus, Hino et al. conducted a follow-up experiment (Experiment 3) that included Kanji non-words that had related characters (i.e., characters within a non-word item were related in meaning). Similar to Experiment 1, they found an ambiguity advantage in reaction time such that polysemes and homonyms were responded to more quickly than unambiguous words, but there was no specific advantage for polysemes over homonyms. Because they found a consistent overall ambiguity advantage, they concluded that semantics must be involved in the processing of both polysemes and homonyms. The authors further concluded that, because of the inconsistent effects, the polysemy advantage reported in the literature is not due to semantic activation of the words' senses as discussed previously, but to feedback from meaning to orthography. Such feedback should be greater the higher the number of meanings/senses associated with a word, which would lead to more feedback from meaning to orthography for ambiguous words than unambiguous words. However, this does not explain why there was a specific advantage for polysemous words in Experiment 2. In this case, the type of non-words used did affect processing speeds across experiments. The experiments discussed previously found differences when the time course of semantic activation of the words' meanings/senses was manipulated, but in this case the overall RTs were consistent across experiments. It could be that the unrelated Kanjinon-words used in Experiment 2 made the related senses of the polysemous words more salient thus facilitating processing of the polysemous words.

Although all the previously mentioned studies attempted to control for important word characteristics, it is difficult to remove all item-level differences between different word types. To avoid this issue, Rodd et al. (2012) examined how learning new related and unrelated meanings to previously known unambiguous words would influence processing. Importantly, the same words were used in the related and unrelated conditions, thus eliminating any differences between stimulus lists. In a series of experiments, Rodd et al. taught participants new meanings for known words that were unambiguous prior to training, and tested learning using a cued recall task. They counterbalanced the training conditions so that each word was paired with a new meaning that was either semantically related or unrelated to the existing meaning, thereby creating polysemes and homonyms, respectively.

In the first two experiments, Rodd et al. (2012) trained the participants on the new meanings via incidental learning in which participants were exposed to the novel meanings of the known words through short passages. The participants recalled vocabulary words with related meanings more accurately than vocabulary words with unrelated meanings. Due to low accuracy on words with unrelated meanings, Rodd et al. modified the training in Experiment 3 to enhance semantic processing of the vocabulary words and their new meanings. They did this by having participants use explicit vocabulary learning methods such as matching vocabulary words with definitions and sentence generation. Participants' accuracy during the cued recall task was higher than in the previous experiments, but accuracy was still higher for words with related meanings than words with unrelated meanings. In addition to the recall task, they used a lexical decision task in Experiment 3; responses to trained words were faster overall than responses to untrained words. Interestingly, responses to trained related-meaning words were faster and less error-prone than responses to trained unrelated-meaning words.

Unlike previous studies that had made comparisons between different word lists, this study replicated the polysemy advantage in lexical decision times for the same set of words using a training paradigm, thus eliminating possible confounds between different stimulus lists. Rodd et al. (2012) argued that the lexical decision data support the notion that semantic similarity facilitates word recognition via richer semantic representations. Under this view, a disadvantage emerges for homonyms because of the inconsistent mappings between the word form and the multiple unrelated meanings, which may lead to weaker connections between the word form and each meaning (Rodd et al., 2004). An advantage emerges for polysemes because, although there is still a one-to-many mapping between the word form and the senses, the senses are related in meaning. Thus, the meanings are less inconsistent with each other than they are for homonyms allowing stronger connections between the word form and each meaning. As a consequence, when one sense of the word is activated, the related senses will be activated more quickly, which may speed up processing.

Up to now, we have reviewed studies that have evaluated the processing of different types of ambiguous words during tasks that require less semantic activation of the words' meanings/senses such as recognizing a letter string as a word in a lexical decision task. Next, we discuss studies that evaluate ambiguous words in more semantically engaging tasks.

More semantically engaging tasks

In this section of the review, we focus on experiments that involve tasks that are more semantically engaging, such as the sense judgment, semantic categorization, and semantic relatedness tasks. These types of tasks lead to greater semantic activation and/or require a specific meaning/sense to be activated to make a correct decision.

Klepousniotou (2002) examined how four types of ambiguous words (homonyms, metaphorical polysemes, metonymous polysemes, and name polysemes) influenced primed lexical decision performance. Name polysemes have one sense that corresponds to a person (e.g., "Picasso" the artist) and a second that corresponds to that person's work (e.g., a "Picasso"). On each trial, participants read a sentence that primed one of the meanings of an ambiguous word. Participants then made a lexical decision to a letter string, which was the target ambiguous word, a control word that matched the critical word's frequency, or a control word that matched the meaning/familiarity frequency of one of the ambiguous word's senses. The primed ambiguous words were responded to more quickly than the control words.

Critically, the results demonstrated differential priming effects for the various types of ambiguous words. Participants responded more quickly to and had a larger priming effect for the metonymous polysemes (e.g., "chicken": the animal vs. the food) than the homonyms. No differences were observed between the other types of ambiguous words. Although no comparisons were made to primed unambiguous words because the study included only ambiguous words, this study shows an overall advantage in processing for metonymous polysemes compared to homonyms. This study also provides evidence that different types of polysemes are processed differently and emphasizes the critical role of semantic similarity between ambiguous word meanings in the processing of ambiguous words.

Hino et al. (2002) examined semantic ambiguity using a semantic categorization task in which particpants were asked to decide whether or not a word belongs to a specific category. Hino et al. found that participants were slower to make semantic categorization (alive or not) judgments for ambiguous than unambiguous words. They argued that the ambiguity disadvantage found in semantic tasks results from the system settling on a specific meaning. Because ambiguous words have more than one meaning, each meaning must be activated, evaluated, and compared with the specific semantic category to finalize a decision. In contrast, Hino et al. (2006, 2010) observed an ambiguity advantage in the lexical decision task, in which settling on a specific semantic code of an ambiguous word is not necessary to make a decision. Out of context, the evaluation of ambiguous words does not require semantics to be completely activated, thus leading to faster response times in lexical decision.

Pexman et al. (2004) also examined ambiguity advantages and disadvantages and tested an alternative explanation, the Decision System Account, which suggests that the difference in ambiguity effects (i.e., a polysemy advantage in lexical decision vs. a homonymy disadvantage in semantic decision tasks) are due to differences in decision-making across tasks. In Experiment 1, Pexman et al. replicated the ambiguity advantage found in lexical decision, but only for the low-frequency ambiguous words used in their study. In Experiment 2, participants performed a relatedness decision task with high- and low-frequency ambiguous and unambiguous words. Importantly, in half of the trials, critical ambiguous words were paired with an unrelated word (e.g., the ambiguous word “punch” paired with the word “short”; “no” trials) and in the other half, critical ambiguous words were paired with a related word (e.g., the ambiguous word “iron” paired with the word “steel”; “yes” trials).

Pexman et al. (2004; Experiment 2) observed an ambiguity disadvantage in the “yes” trials, and found no ambiguity effect in the “no” trials. Post hoc regression analyses demonstrated that, in the “yes” trials, ambiguous words were responded to more slowly and less accurately than unambiguous words, and more semantically related word pairs were responded to more quickly and accurately than less semantically related word pairs. However, although ambiguity did not affect the “no” trial responses, there was an effect of semantic similarity such that more semantically related word pairs were responded to more slowly than less semantically related word pairs. Because they included different words in the “no” and “yes” trials and did not examine the role of meaning dominance, they ran a follow-up experiment (Experiment 3) using the same task, but controlled for stimulus list and dominance effects. Once again, they found an ambiguity disadvantage only for “yes” trials, regardless of whether the ambiguous word was paired with a word related to its dominant or a subordinate meaning/sense.

Because prior lexical decision studies (e.g., Klepousniotou et al., 2008; Rodd et al., 2002) reported advantages for polysemes, Pexman et al. (2004; Experiment 5) examined whether a polysemy advantage would also emerge in a semantic relatedness task. They replicated their previous findings of an ambiguity disadvantage only for the “yes” trials. They also observed that participants were faster to respond to polysemes than to homonyms. However, this effect was also found only for the “yes” trials. Pexman et al. posited that these differing ambiguity effects are not due to semantic factors but instead to decision making processes. According to their Decision System Account, an ambiguity disadvantage is found in “yes” trials for semantic tasks because one sense of the ambiguous word is unrelated to the word pair, which leads to response competition—one meaning of the ambiguous word is related, which would activate a “yes” response, but another meaning is unrelated, which would activate a “no” response. With more related senses, there is a smaller cost for ambiguous words because both senses may be closely related to the pair. In “no” trials, the multiple meanings of the ambiguous word are unrelated to the unambiguous target word and therefore there is no response competition. Further, because the multiple meanings are unrelated, the relatedness of the senses/meanings of the ambiguous word influences processing to a lesser extent.

Using the semantic categorization task, Hino et al. (2006) sought to replicate the previous null effect of ambiguity in “no” trials while manipulating sense overlap effects. Participants in the study judged whether Katakana Japanese words were labels of a living thing (Experiment 2), a vegetable (Experiment 3), either an animal or a vegetable (Experiment 4), or the title of a job (Experiment 5). In all four experiments, the experimental items (unambiguous words, polysemes, and homonyms) were included in the negative or “no” trials. In Experiment 2 (living thing category) and 5 (job category), Hino et al. found a significant ambiguity disadvantage such that participants responded more slowly and less accurately when responding “no” to homonyms than unambiguous words. Participants responded more quickly and accurately when processing polysemes than homonyms. No ambiguity effects were observed when participants decided whether or not a word was a vegetable (Experiment 3), or when they decided if a word was an animal or vegetable (Experiment 4). Again, Hino et al. attributed the different ambiguity effects to decision-making differences rather than semantic activation of the words’ meanings/senses. Hino et al. argued that relatedness of meanings and ambiguity effects were found in Experiments 2 (alive category) and 5 (job category) because these categories were broader than those used in Experiments 3 (vegetable category) and 4 (animal or vegetable category). Therefore, making a decision within a narrower category will take fewer comparisons to reach a conclusion than making a decision within a broader category, thus supporting the Decision System Account. The response times in Experiments 2 and 5 were longer than in Experiments 3 and 4, which is consistent with the idea that more comparisons had to be made to finalize a decision. However, alternative accounts have also been suggested, including the Settlings Dynamics Account (Armstrong & Plaut, 2008; 2011), which is described in more detail in the Discussion: Processing Issues section.

The sense judgment task has also been used to examine processing and representation differences between ambiguous and unambiguous words. In this task, participants are asked to decide if two word pairs “make sense.” The critical comparison is between when the word pairs refer the same meaning/sense (e.g., daily paper vs. magazine paper) and when the word pairs refer to different meanings/senses (e.g., daily paper vs. wrapping paper). Klein and Murphy (2001) used the sense judgment task and memory tasks to examine the representational and processing differences of ambiguous words. In Experiment 1, Klein and Murphy evaluated participants' memory for polysemes depending on how the words were embedded in phrases. Participants first studied phrases such as "liberal paper", then, after the study phase, participants saw phrases containing studied items that were consistent with the meaning of the studied sense such as "daily paper" and phrases that were inconsistent with the meaning of studied sense such as "wrapping paper". The participants showed a consistency effect in that they were more likely to correctly recognize a word with a same sense modifier than a word with an inconsistent sense modifier. In Experiment 2, participants were asked to judge whether or not two word pairs "made sense". In this task, the target word pair was preceded by a consistent sense (e.g., wrapping paper, shredded paper) or an inconsistent sense pair (e.g., wrapping paper, liberal paper). Participants were faster to make sense judgments when the two pairs corresponded to the same sense than when they corresponded to different senses. They concluded from these findings that polysemous word senses must be stored separately because, if polysemous word senses share a core meaning and are stored together, then there would not be a reliable consistency effect.

Klein and Murphy (2001) conducted a follow-up experiment (Experiment 3) and included homonyms in the stimulus list, which allowed them to make comparisons between these two types of ambiguous words. Klein and Murphy found that homonyms and polysemes both showed a significant consistency effect, and that the magnitude of this effect was similar between the two word types. This is surprising because a larger consistency effect would be expected for homonyms than polysemes because the meanings are so distinct. Furthermore, based on previous research, it was expected that participants would have made judgments about polysemes faster than judgments about homonyms, but no overall differences were found between these ambiguous word types. However, the results are consistent with Pexman et al. (2004), who also did not find a polysemy advantage in the semantic judgment task. It is possible that the results of this study may reflect the type of stimuli that Klein and Murphy used. Specifically, the polysemes they used varied greatly in semantic similarity, and were closer to homonyms than true polysemes (see Foraker & Murphy, 2012, for relatedness ratings).

Using a method similar to the one used by Klein and Murphy (2001), Brown (2008) examined differences between polysemes and homonyms but focused on verbs instead of nouns. Critically, they also examined the semantic similarity between the ambiguous words such that phrases contained polysemes with closely related senses (e.g., "broke the glass" vs. "broke the radio"), polysemes with distantly related senses (e.g., "ran the track" vs. "ran the shop"), and homonyms (e.g., "banked the plane" vs. "banked the money"). Additionally, they included phrases containing unambiguous verbs as a comparison group (e.g., "cleaned the shirt" vs. "cleaned the cup"). Participants read a pair of phrases and were asked to decide if the phrases "made sense". The nonsense trials contained phrases that were anomalous and/or semantically incoherent (e.g., "hugged the juice" vs. "hugged the fund", "joined the cliff" vs. "joined the team"). Participants responded more quickly and accurately to phrases that had a same-sense verb than phrases that had a different-sense verb, replicating the consistency effect. Homonym verb phrases yielded the slowest and least accurate responses overall. Closely related polysemous verbs showed an accuracy and RT advantage over more distantly related polysemous verbs. Further, there was a significant linear trend such that participants responded more quickly and accurately as the meanings/senses of the ambiguous words increased in semantic similarity. Counter to Klein and Murphy (2001), Brown (2008) found an advantage for polysemes over homonyms in RT and accuracy, thereby demonstrating that a polysemy advantage can emerge in more semantically engaging tasks. The linear trend in their data suggests that there may not be a clear distinction between polysemes and homonyms, but rather that processing reflects a more continuous nature of ambiguity that corresponds to the degree of semantic similarity of the multiple senses.

Klepousniotou et al. (2008) also sought to replicate Klein and Murphy's (2001) findings; however, they additionally examined meaning dominance and ambiguous word sense overlap. The critical stimuli included words with highly overlapping senses (e.g., "chicken" the animal vs. the food), moderately overlapping senses (e.g., "ground" the floor vs. a place to camp), and non-overlapping senses (e.g., "key" to a lock vs. on a typewriter). There were two related modifiers for each meaning of the ambiguous items. Participants first saw a modifier–target word pair that corresponded to the subordinate sense (conflicting context; e.g., mental block), the dominant sense (cooperating context; e.g., toy block), or neither sense (neutral context; e.g., **** block) and then were presented with a modifier–target word pair that could relate to either the dominant sense ("dominant condition"; e.g., wooden block) or to the subordinate sense ("subordinate condition"; e.g., mental block). Participants were asked to decide if the phrases made sense (e.g., "yes" response: prime: mental block, target: wooden block; "no" response: prime: hair comb, target: card comb). In filler trials (i.e., "no" response trials) participants first saw a phrase that did make sense followed by a phrase that did not make sense. Results were inconsistent with those of the Klein and Murphy (2001) study but consistent with those of Brown (2008), in that participants were faster to make sense judgments to polysemous word pairs with highly overlapping senses compared to ambiguous words with moderately to non-overlapping senses. They additionally found a significant sense overlap by dominance interaction, such that in the dominant condition, participants were equally fast to make sense judgments to the cooperating and conflicting pairs but only for the highly overlapping senses. By contrast, in the subordinate sense condition, participants responded more slowly to the conflicting pairs than the cooperating pairs for all levels of sense overlap. Furthermore, in this condition, the difference between the conflicting and cooperating conditions was twice as large for the moderately and low overlapping sense conditions than the highly overlapping conditions. This suggests that dominance may influence processing less for ambiguous words with more overlapping senses than for ambiguous words with less overlapping senses. Additionally, these results emphasize that not all ambiguous words are processed similarly, and that the amount of semantic similarity between the senses influences how ambiguous words are processed and comprehended. The authors proposed that this provides additional evidence for the single-entry model of polysemous word representation for the polysemes with highly overlapping senses.

The studies reviewed above have used tasks that either provide no context for the words' meanings/senses or provide a simplified context for the words' meanings/senses. However, in natural language use, words are embedded in sentence and discourse level contexts that provide varying degrees of contextual support for the multiple meanings/senses of the ambiguous words. A more recent study by Foraker and Murphy (2012) examined how sense dominance and context influence the processing of polysemous words embedded in sentences, thus providing a more natural context. Foraker and Murphy used the same polysemous words used by Klein and Murphy (2001) allowing for comparisons to be made across these experiments. The polysemous words and the dominance of the senses were classified using the dictionary method. In Experiment 1, they designed their sentence stimuli so that the first sentence provided either a biasing context for the dominant sense (e.g., The fashion designers discussed the *cotton*), for the subordinate sense (e.g., The farm owners discussed the *cotton*), or a neutral context (e.g., They discussed the *cotton*). The second sentence was related either to the dominant sense (e.g., The fabric was not what they had been hoping for), or to the subordinate sense of the ambiguous word (e.g., The crop was not what they had been hoping for). They hypothesized that, if polysemous senses share a core meaning, then there should be little difference between the dominant and subordinate senses on reading times of the second sentence in the neutral context condition. However, they found that participants were faster at reading the second sentence when it supported the dominant sense of the polysemous word than when it supported the subordinate sense.

In Experiments 2 and 3, Foraker and Murphy (2012) used a single-sentence design to reduce the possibility that sentence boundaries exaggerated dominance effects. Experiment 2 used a moving window paradigm similar to Experiment 1. Again, shorter reading times for disambiguating regions associated with the dominant sense than the subordinate sense were found. However, this effect was less pronounced than in Experiment 1, and was only marginally significant. Experiment 3 used eye-tracking to obtain more temporally sensitive measures of processing. There were longer reading times for subordinate senses in the neutral context condition in first-pass reading measures and marginally longer reading times for the subordinate senses in the wrap-up region (i.e., the area after the disambiguating information). For regression path duration (the time from first entering the region until it is exited to the right), there was a marginal effect of dominance such that participants reread the sentence more often when the disambiguating region biased the subordinate sense. Foraker and Murphy additionally examined how dominance and semantic similarity of the senses affected reading times. They found a significant interaction between dominance and semantic similarity on the polysemous noun for early measures and total time, such that words with a highly related senses and a highly dominant sense were more difficult to process. These results demonstrate that dominance and semantic similarity both affect processing of these words in a more natural context like reading.

However, there are several reasons why these results may differ from those of previous studies. Importantly, the polysemous words were selected so that there was a wide range in semantic similarity between the senses. Foraker and Murphy (2012) did find an effect of semantic similarity on readings times, but did not find a sense relatedness by dominance interaction. However, there were only 25 items, which may not be a sufficient number to reveal such an effect. Prior studies have shown that various types of polysemous words yield different results (e.g., Klepousniotou et al., 2008). It is therefore possible that the results differed from prior studies because of the choice of stimuli. Future research should use similar methodologies along with different types of ambiguous words to elucidate the role of semantic similarity and dominance.

Thus far, we have reviewed studies that reported advantages in processing for polysemes and all ambiguous words, disadvantages for homonyms, and null effects. Few studies have consistently yielded both polysemy advantages and homonym disadvantages using the same task. Therefore, the different effects reported could be due to task differences as suggested by Hino et al. (2006), or due to differences in semantic activation of the words' meanings/senses as suggested by some PDP accounts (e.g., Rodd et al., 2004).

Using a PDP framework, Armstrong and Plaut (2008) simulated ambiguity effects by examining different stages of processing. They hypothesized that the differential ambiguity effects (the polysemy advantage and the homonym disadvantage) found in the literature are not entirely due to task differences or decision making differences as suggested by other researchers (e.g., Pexman et al., 2004; Hino et al., 2006). Instead, they argued for a different account, the Settling Dynamics Account, in which differences are due to the amount of semantic activation or precision needed to perform the task. In Armstrong and Plaut's model simulations, earlier stages in processing were considered comparable to less semantically engaging tasks (e.g., lexical decision) and yielded a polysemy advantage, whereas later stages in processing were considered comparable to more semantically engaging tasks (e.g., semantic categorization) and led to a homonym disadvantage; stages in the middle resulted in both effects simultaneously. In the behavioral portion of Armstrong and Plaut's (2008) study, they manipulated "semantic precision" or the level of semantic activation of the system by increasing the difficulty of the non-words in a lexical decision task using the same stimuli and manipulations as Rodd et al. (2002). In particular, Armstrong and Plaut's easy non-words matched the non-words used by Rodd et al. (2002) in bigram frequency, the hard non-words contained the highest bigram frequencies, and the medium difficulty condition contained non-words with bigram frequencies that were between those in the easy and hard conditions. Therefore, in the hard condition, the non-words most resembled real words. They found a polysemy advantage in the easy and middle conditions and a homonym disadvantage in the middle and hard conditions.

In a follow-up study, Armstrong and Plaut (2011) attempted to induce a polysemy advantage while also inducing a homonym disadvantage, but with a more carefully selected set of stimuli. The authors pointed out that, in their previous work (Armstrong & Plaut, 2008), the ambiguous words did not all have balanced meanings/senses. Therefore, in this follow-up study, they carefully selected items that had more balanced senses to maximize competition between them. They manipulated the visual quality of the stimuli (either high contrast or low contrast) and the non-word difficulty as previously described. Degrading stimulus quality slows down responses and therefore may tap later stages of semantic activation of the words' meanings/senses. They also argued that slowing response times in this way might lead to ambiguity effects similar to those reported in auditory lexical decision tasks. Slowing down responses in different ways allowed Armstrong and Plaut to contrast their alternative account of semantic ambiguity effects, the Settling Dynamics Account, with the Decision

System Account (e.g., Hino et al., 2006; Pexman et al., 2004). In this study, Armstrong and Plaut also examined more types of ambiguous words including homonyms, polysemes, unambiguous words, and hybrid ambiguous words, which have both polysemous senses and homonymous meanings.

In the low contrast/easy non-word condition, Armstrong and Plaut found a homonym disadvantage and a marginal polysemy advantage in the RT analysis and a significant polysemy advantage and marginal homonym disadvantage in the accuracy analysis. The low contrast/difficult non-word condition led to a polysemy and hybrid word advantage, but not a homonym disadvantage. The difficult non-words did not induce a homonym disadvantage, but did yield a significant polysemy advantage in the RT and accuracy analyses. The pseudohomophone non-word condition yielded only a polysemy advantage in the RT and accuracy analyses. The hybrid ambiguous words tended to yield response times similar to those yielded by the polysemes, suggesting that the semantic similarity of the senses was a more influential factor than the competing dissimilar meanings. Finding these two effects only in the degraded stimulus condition is suggestive of a highly interactive system in which orthography and semantics jointly impact performance.

Electrophysiological/imaging studies

In addition to behavioral methods, researchers have also used imaging and electrophysiological methods such as event-related potentials (ERPs), and magnetoencephalography (MEG) to examine semantic ambiguity. These studies have focused primarily on the theories of representation of ambiguous words. Although behavioral measures provide insight to how the mind processes different types of ambiguous words, they may not reveal more temporally sensitive differences that ERP and MEG data may show (e.g., Hargreaves, Pexman, Pittman, & Goodyear, 2011). Many of the behavioral tasks discussed above have been replicated using these methods, which may provide more insight into how these words are processed and represented. One such MEG study by Pylkkänen et al. (2006) used a similar task and materials as Klein and Murphy (2001). In particular, they asked participants to make sense judgments on word phrases that contained a homonym (e.g., river bank, savings bank), a polysemous word (e.g., lined paper, liberal paper), or two semantically related words (e.g., lined paper, monthly magazine). Pylkkänen et al. (2006) examined the M350 component, which is thought to represent lexical and morphological root access. Earlier peaks of the M350 components for the related-sense compared to unrelated-sense condition would represent priming between the multiple senses of the polysemous words and not competition between the senses as may be expected for homonym meanings. They hypothesized that, if polysemous senses share a morphological root but have distinct sense representations, the M350 should reveal a shorter peak latency for the related- than the unrelated-sense condition and no effect of relatedness for homonyms. Conversely, they hypothesized that if polysemous senses were stored as separate lexical entries and do not share a morphological root (like homonym meanings), then the M350 effects would be similar to the homonyms such that the peak M350 would indicate less priming from one sense to the other. The behavioral data revealed no differences between homonyms and polysemes, similar to the effects found by Klein and Murphy (2001).

Interestingly, the MEG data did reveal significant differences between the word types. In the left hemisphere, the mean peak latency for the M350 was significantly earlier for related pairs than unrelated pairs for polysemous words. However, the mean peak M350 latency was significantly later for the related homonym pairs compared to the unrelated homonym pairs. They also found differences in right hemisphere M350 mean peak latencies such that the polysemous words showed the opposite effect of the left hemisphere. Because polysemous senses did prime each other as indicated from the earlier M350, they concluded that these data are consistent with the single entry hypothesis of polysemous word representation. Further, this study demonstrates that electrophysiological data sometimes reveal early lexical effects that behavioral data do not always capture (e.g., McLaughlin, Osterhout, & Kim, 2004). However, the method used in this study requires participants to activate the multiple senses and meanings of ambiguous words, which may exaggerate the effects of similarity (for polysemes) and dissimilarity (for homonyms).

Another MEG study conducted by Beretta et al. (2005) used the M350 effect to explore the representation of ambiguous words. They used a lexical decision task so that participants' initial reading of the word would not be contextualized by a previous phrase (as in the two-phrase sense judgment task). Therefore, this method could reveal early lexical access effects that do not draw the participants' explicit attention to the multiple senses. Beretta et al. used the words from the Rodd et al. (2002) study, which included unambiguous words with few senses, polysemous words with many senses, homonymous words with many senses, and homonymous words with few senses. They examined whether the M350 component showed a dissociation from the behavioral RTs. Based on results a dissociation between the M350 component and behavioral RT occurs when manipulated factors affect lexical activation and decision-making independently. Beretta et al. hypothesized that, if polysemous words are represented in separate lexical entries, they should show a similar M350 peak latency to homonyms, but faster RTs than homonyms (based on Rodd et al.'s findings). They hypothesized that, if polysemous words are represented together in a single lexical entry, then polysemous words should show an earlier M350 peak latency than homonyms as well as faster RTs for polysemes.

Words with many senses were responded to more quickly than words with fewer senses, and homonymous words were responded to more slowly than polysemous words. Similar to the Pylkkänen et al. (2006) study, polysemous words revealed an earlier peak M350 latency compared to homonyms. Words with more senses also had an earlier peak M350 latency than words with fewer senses. The MEG data showed differences in peak M350 latencies between polysemous and homonymous words that directly mirror the RT effects. The authors concluded that these data support the single lexical entry model of polysemous word representation. However, it remains unspecified why polysemous words had an earlier M350 peak latency than unambiguous words, which presumably also have a single lexical entry.

As previously reported, different types of polysemous words can yield different effects, and therefore may be represented differently (e.g., Klepousniotou, 2002). To examine those effects further, Klepousniotou et al. (2012) examined differences in processing between homonyms and different types of polysemous words in a primed lexical decision task while measuring ERPs. They examined both balanced and unbalanced homonyms, and metonymous and metaphorical polysemes. Each word was paired with a related and unrelated prime that corresponded to each of the words' meanings/senses. They examined the N400 component which is a measure of semantic integration and priming, such that a reduced N400 corresponds to greater priming. Thus, they examined whether the distinct meanings/senses of the polysemous and homonymous words could prime each other as measured by the N400. Because they chose to employ a delayed lexical decision design, the RT data did not yield any significant effects of word type. However, the electrophysiological data did reveal significant effects of target type, such that dominant primes for unbalanced homonyms led to a greater reduction of the N400 amplitude than subordinate primes, indicating a significant priming effect.

Further, the subordinate priming effect was observed mostly over the left hemisphere, whereas the priming effect for the dominant primes was observed over both hemispheres. For balanced homonyms and for metonymous polysemes, both the subordinate and dominate meaning primes led to a reduced N400 effect. No differences were observed across hemispheres. Lastly, for metaphorical polysemes, there was a graded reduction of the N400 amplitude, such that the dominant primes led to more reduction in N400 amplitude than the subordinate primes. Further, the N400 priming effect was found predominantly over the right hemisphere for metaphorical polysemes, unlike the subordinate primes for the unbalanced homonyms. The ERP record thus clearly demonstrates differences in processing between different types of ambiguous words. The authors also suggest the differences across hemispheres may indicate different neural generators contributing to the priming effects for the different types of ambiguous words, although they did not use source localization techniques to confirm this.

Discussion: processing issues

Early research on semantic ambiguity focused on the time course of meaning activation, meaning dominance, and context effects in semantic ambiguity resolution. The Klepousniotou (2002) and Rodd et al. (2002) studies prompted researchers examining ambiguity to focus on the differences between the types of semantically ambiguous words and the relatedness of the senses/meanings of these words. Although several researchers have found ambiguity advantages only for words with highly related senses (e.g., Armstrong & Plaut, 2008, 2011; Brown, 2008; Klepousniotou, 2002; Klepousniotou & Baum, 2007), some other researchers have found an ambiguity advantage for homonyms (Lin & Ahrens, 2010), or have found null effects (Hino et al., 2006; 2010). The ambiguity disadvantage that emerges in semantic tasks is also not consistently found. Some researchers have found the ambiguity disadvantage with semantic categorization (e.g., Hino et al., 2002) and semantic relatedness tasks (Pexman et al., 2004), whereas other researchers have found null effects for "no" trials (e.g., Pexman et al., 2004).

There are several reasons why there may be inconsistent results in the semantic ambiguity literature. One of the main reasons is that the stimuli often differ across experiments. Although some researchers (e.g., Armstrong & Plaut, 2008; Beretta et al., 2005) have used the same word stimuli or categories as Rodd et al. (2002), the non-word stimuli varied. Some experiments used pseudohomophones, whereas others used pronounceable non-words. The use of pseudohomophones as non-words may lead the participants to engage in more semantic processing during a lexical decision task, whereas pronounceable non-words may lead to a more orthographically and less semantically based strategy during a lexical decision task. However, this was not always found because Klepousniotou and Baum (2007) found an advantage for metonymous polysemes in lexical decision tasks that did not use pseudohomophones. It would be very useful for researchers in this area to provide complete stimulus lists (including non-words), to facilitate cross-experimental comparisons. Additionally, ambiguity effects have been tested in several languages (e.g. Mandarin Chinese, Japanese, and English). The studies using Japanese (e.g., Hino et al., 2006; Pexman et al., 2004) have implemented mixed scripts (i.e., Katakana, Kanji) during the tasks. Although it was deemed necessary to use a combination of mixed scripts to investigate ambiguity effects in Japanese speakers, it is unknown how much of the findings were due to this manipulation, and this cannot be replicated in single-script languages. One would expect that if the language system is similar across languages, ambiguity effects should replicate across languages. And, indeed, several phenomena such as the ambiguity advantage in the lexical decision task have been replicated across languages (Hino et al., 2002; Klepousniotou & Baum, 2007; Lin & Ahrens, 2010).

The type of ambiguous words tested and how the ambiguous words are defined and classified (using the dictionary vs. norms vs. linguistic rules) also differ greatly across experiments. Most of the research done in this area has taken a categorical approach to classifying ambiguous words. Such a categorical approach could exaggerate some effects or mask others, especially because these operationalizations of these categories tend to vary across studies (e.g., “unambiguous words” may have only one meaning or simply fewer meanings than “ambiguous” words). In fact, researchers who make fine-grained linguistic distinctions between different types of polysemes (e.g., metonymous polysemes, metaphorical polysemes, and name polysemes) do find differences in processing between the different types of polysemes (e.g., Klepousniotou, 2002; Klepousniotou & Baum, 2007; Klepousniotou et al., 2008, 2012; see also Rabagliati & Snedeker, 2013 for similar results using a picture-naming task). Grouping the different types of polysemes into one category could dilute the effects and lead to faulty or incomplete conclusions. Using meaning/sense relatedness norms rather than using published lists or the dictionary method to define the type of ambiguous word would also allow researchers to better capture the continuous nature of ambiguity. Thus, researchers making theories and hypotheses about ambiguity representation and processing should be aware that the polyseme versus homonym distinction is limited and may not reflect how humans actually process ambiguous words and their meanings/senses.

Prior studies (e.g., Duffy et al., 1988; Vu et al., 1998) demonstrated that meaning frequency is an important factor in ambiguity resolution, but this issue has been less well examined for polysemous words. In experiments that are based on semantic decisions (and thus meaning activation), sometimes unbalanced ambiguous words were used, and sometimes balanced ambiguous words were used. Given the previous findings, this is an issue that should be investigated for ambiguous words with varying levels of meaning/sense similarity. In particular, there may be differences in processing and representation between a more frequent sense of a polyseme versus a more frequent meaning of a homonym. Lastly, part of speech has not always been controlled across experiments and across conditions within experiments. Several studies have shown that nouns and verbs are processed and represented differently. Although a full treatment of how word class affects semantic ambiguity is beyond the scope of this review, some previous research has explored how semantic and word class ambiguity interact (e.g., Lee & Federmeier, 2009; Mirman, Strauss, Dixon, & Magnuson, 2010; Rodd, Longe, Randall, & Tyler, 2010). Future research would benefit from examining and controlling for word class in studies examining ambiguity effects.

Despite the differences across studies, there are some patterns that emerge from the data. As expected, the majority of experiments found overall differences between ambiguous words and unambiguous words. When no differences were observed, it was in specific cases in which participants were responding "no" in a semantic categorization task or in a semantic relatedness task (Hino et al., 2004; Pexman et al., 2006). Semantic similarity between the meanings or senses of the ambiguous words across several studies facilitated word recognition in comparison to that of unambiguous words (e.g., Beretta et al., 2005; Klepousniotou & Baum, 2007; Rodd et al., 2002), whereas semantic dissimilarity in the meanings or senses of the ambiguous words slowed word recognition in comparison to that of unambiguous words (e.g., Rodd et al., 2002), especially when difficult non-words were used (e.g., Armstrong & Plaut, 2011). Competition between multiple unrelated meanings slows semantic relatedness decisions relative to unambiguous words, but only in trials that are related to a single meaning of the ambiguous word (i.e., "yes" trials; Pexman et al., 2004). Semantic similarity between the multiple senses facilitated semantic relatedness decisions relative to homonyms, but again only on trials in which only one sense is related to the unambiguous word (Pexman et al., 2004). Broader semantic categorization decisions yielded a disadvantage in processing speed for homonyms relative to unambiguous words and an advantage in processing speed for polysemes relative to homonyms in "yes" and "no" trials (Hino et al., 2006).

Overall, the majority of the research we have discussed suggests that semantic similarity is an important factor in processing and representation because certain types of polysemous words with more related senses (e.g., metonyms) show processing advantages more consistently than homonyms and polysemes with less related senses (e.g., metaphors). Additionally, several studies emphasize the importance of the timing of the decision across different tasks and that when decisions are made later due to changes in foils (e.g., changing the difficulty of the non-word, or making a "yes" vs. "no" decision), the type of task or the modality of the task (e.g., auditory vs. visual), some processing advantages and disadvantages may emerge for some types of ambiguous words and some processing advantages and disadvantages may disappear for some types of ambiguous words. We now review how recent PDP models account for processing differences between polysemes and homonyms.

Rodd et al. (2004) proposed a model to explain differences in processing between polysemes and homonyms (see Fig. 1). The connectionist model they proposed develops deep attractor basins as the network learns to differentiate the different meanings of homonyms. On the other hand, the network develops wide, shallow attractor basins for the multiple senses of polysemes. Rodd et al. suggested that, during word recognition, homonyms initially enter a blend state at the semantic layer in which the specific meaning has not been selected. With time and accumulated evidence, the network settles on a specific meaning. According to the model, the disadvantage reported in previous studies for homonyms (e.g., Rodd et al., 2002) is due to this shift from a blend state into a specific meaning state. For polysemes, the multiple related senses correspond to similar points in semantic space so there is no need to move from away from a blend state during lexical decision, thus word recognition is facilitated for words with multiple related senses. Rodd et al. (2004) have directly applied this model to performance with homonyms and polysemes in the lexical decision task, but did not explicitly extend it to additional tasks. However, with some additional assumptions about the requirements of various tasks, this model may explain additional data.

Armstrong (2012) proposed an account of semantic ambiguity resolution that was specifically designed to explain ambiguity effects on a wider range of tasks than Rodd et al.'s (2004) model, which was designed to explain these effects in lexical decision. This Settling Dynamics Account is set within the PDP framework and takes into consideration the distinction between polysemes, homonyms, and unambiguous words, as well as temporal and contextual aspects of semantic activation of word meanings. Importantly, the model distinguishes activation patterns for contextually appropriate and inappropriate meanings of homonyms and polysemes (see the predicted semantic activation curves in Fig. 2).

In the framework of the Settling Dynamics Account, there are excitatory and inhibitory connections between the features of the words: polyseme senses mainly have excitatory connections between them and homonym meanings mainly have inhibitory connections between them. During earlier stages of processing and context-free processing, semantic activation of the meanings/senses is predominated by excitatory connections for polysemes and inhibitory connections for homonyms. For later processing and context-dependent tasks, semantic activation is predominated by competition between the senses/meanings. This earlier portion of the polysemous curve demonstrates the higher semantic activation due to the excitatory connections between the senses, which is consistent with findings of studies that report a polysemy advantage (i.e., faster responding) in lexical decision tasks (Armstrong & Plaut, 2008, 2011; Rodd et al., 2002). For later processing or context-sensitive tasks, the activation of polysemous word senses begins to stabilize. As the contextually appropriate sense is activated, the semantic activation of features associated with that sense increase as the semantic activation for features associated with the inappropriate sense decrease. This part of the curve is consistent with null processing effects found for polysemes, and disadvantages for homonyms found in tasks that engage semantics to a greater extent (Hino et al., 2006, 2010; Pexman et al., 2004).

For homonyms, there is less semantic activation relative to polysemes and unambiguous words due to competition and the lack of shared features between the meanings. However, the semantic activation initially would not be different from that for unambiguous words. This is because homonyms and unambiguous words lack the cooperating excitatory connections from related senses that polysemes have. Furthermore, although there are more features associated with homonyms, the meanings inhibit each other, leading to similar activation levels as the unambiguous words. The Settling Dynamics Account proposes that the activation of both the contextually appropriate and inappropriate homonym meanings will increase over the time course of processing, with greater inhibitory effects and competition between the appropriate and inappropriate meanings leading to a disadvantage in processing. The part of the activation curve just prior to the blend state is consistent with the marginal disadvantages found for homonyms in lexical decision tasks (Armstrong & Plaut, 2008, 2011; Rodd et al., 2002). During later processing and context-dependent tasks, the semantic activation for the features associated with the appropriate meaning of a homonym will increase as the semantic activation for the features associated with the inappropriate meaning decreases. This part of the curve after the blend state corresponds well with homonym disadvantages reported for semantic categorization (Hino et al., 2006; 2010; Pexman et al., 2004), semantic decision tasks (Klein & Murphy, 2001), and reading time (e.g., Binder & Rayner, 1998; Duffy et al., 1988; Sereno et al., 2006). This recent account of ambiguity resolution provides a mechanistic explanation for the varying phenomena observed in the semantic ambiguity literature and accounts for differences between different types of ambiguous words. This account also has a temporal aspect that allows one to make predictions for various points in processing as semantic activation changes.

Discussion: representational issues

Although Klein and Murphy (2001) and Foraker and Murphy (2012) provide evidence that polysemous words are processed similarly to homonyms, the majority of results discussed in this review provided evidence that the polysemes are processed differently from homonyms. Despite this, the question of how these words are represented in the mental lexicon remains. In the literature, there seems to be little debate regarding how homonyms are represented —there appears to be a consensus that homonym meanings are stored separately in the mental lexicon. The logic behind this conclusion is that homonyms are two separate words that happen by chance to have the same word form, and therefore they should not be stored together. By contrast, polysemes often have shared etymological roots, so the senses of polysemes are historically connected in meaning. This distinction is also represented in dictionary definitions. But without formal training in etymology, humans are likely unaware of such connections. Researchers suggest that the polysemy advantage found in sense judgments and lexical decision tasks indicates that polysemous word senses are stored together in the same lexical entry. However, this advantage could reflect early semantic effects in processing. For example, PDP models would predict processing advantages for polysemes via facilitatory connections between the semantically similar senses, which homonym meanings lack.

An important aspect of the reviewed studies in that the theories of the representation of ambiguous words are based on established meanings and senses and therefore assume a static representation of the mental lexicon. However, new meanings and interpretations of words can be learned or derived on the fly, which would alter the connection of the word with its established meaning(s) and or senses (see, e.g., Srinivasan & Snedeker, 2011, for an example of such learning in children). In adults, Rodd et al. (2012) demonstrated the flexibility of mental representations of established word forms and meanings in a training study. With five days of training, participants were able to induce ambiguity effects in lexical decision for words that were considered unambiguous prior to training. These studies beg the question of how ambiguous word processing changes along with vocabulary and conceptual knowledge. Examining these changes over time may provide more insight to the understanding of ambiguous word representation and processing.

General discussion

Based on the studies reviewed here, it is clear that semantic ambiguity influences processing across a wide range of tasks. Although semantically ambiguous words in general are processed differently than unambiguous words, there is also compelling evidence that different types of ambiguous words are processed differently than each other. Polysemes in general appear to be processed with more ease than homonyms (e.g., Armstrong & Plaut, 2011; Frazier & Rayner, 1990; Klepousniotou, 2002; Klepousniotou et al., 2008; Rodd et al., 2002). But, within the category of polysemes, different effects are also observed between metonymous and metaphorical polysemes such that metonyms are processed more quickly than metaphors (e.g., Frisson & Pickering, 2001; Klepousniotou, 2002; Klepousniotou et al., 2008, 2012; see McElree et al., 2006, for evidence regarding different types of metonyms). We have reviewed lines of research that focused on processing differences between different types of ambiguous words. How do these results from various perspectives inform us about a model of ambiguity resolution? What mechanism likely yields such varying results? We first discuss how polysemes and homonyms differ and how semantic similarity between the multiple senses and meanings affect the processing and representation of these words types. We then discuss how experience-based models may be used to understand how ambiguous words are learned, processed, and represented in the mind.

Based on prior assumptions and theories of how concepts are stored in the human mind, more semantically related concepts are connected or linked more closely in the neural network compared to less semantically related concepts (Collins & Loftus, 1975), which is supported by the semantic priming literature (see Neely, 1991, for a review). Following that assumption, the meanings or senses of a polyseme are likely to be more closely connected than the meanings of a homonym. Regardless of how these words are represented, the senses of polysemes would activate each other in the semantic network, but the meanings of homonyms would be less likely to activate each other via spreading activation. However, because the meanings and senses are also connected to a shared orthographic/phonological form, the semantic relationship between the meanings or senses is more complicated than for unambiguous words. There may be inhibition among the multiple meanings or even facilitation via spreading of activation through the shared orthographic/phonological word form. Polysemes and homonyms show facilitation when primed with a supporting context compared to a neutral context, and this facilitation is greater when the context biases the dominant meaning or sense of the ambiguous word. Facilitation for polysemes could be due to the added semantic activation coming from the similar senses. Alternatively, facilitation also could be due under-specification of meaning in the semantic code for polysemes (e.g., Frisson & Pickering, 2001). It would be predicted that dominance would influence processing of polysemes less than homonyms, due to the shared features among the multiple senses (e.g., Frazier & Rayner, 1990).

Recent studies have indeed found a reduced or null effect of dominance for polysemes (e.g., Klepousniotou et al., 2012), such that no differences were observed between dominant and subordinate primes in behavioral and in the ERP record. Although Foraker and Murphy (2012) did find a dominance effect for polysemes in their study, close to half of the polysemes had semantic similarity ratings between the senses that were below 3.5 on a 7-point Likert-type scale with 1 representing "completely different" and 7 representing "almost identical", suggesting that their polysemes were more similar to homonyms. This may have led to greater dominance effects. Foraker and Murphy, however, did find a significant interaction between dominance and semantic similarity such that the readers found it more difficult to process polysemes that had a highly dominant sense and highly semantically similar alternative sense(s). Although it was their intent to include polysemes with less semantically related senses, as discussed earlier, the type of polysemes tested (e.g., metonyms vs. metaphors) can result in different outcomes. Thus, it would be predicted that as the senses of polysemes become less semantically similar, the dominance effect will become stronger. That is, ambiguous words with less semantically similar senses/meanings would demonstrate a stronger dominance effect in processing than ambiguous words with more semantically similar senses/meanings. With this in mind, we next discuss how an instance-based approach may provide a greater understanding of semantic ambiguity resolution.

Changes in meanings over time

When learning a language, each instance of an unambiguous word maps relatively consistently from the orthographic and/or phonological level onto the semantic representation in memory. This is not the case for the learning of ambiguous words. Each experience with the ambiguous word could consistently map to a prior instance of the word in which the semantic representation is the same or closely related, or could inconsistently map to a prior instance in which a different semantic interpretation was instantiated. Through this experience of learning inconsistent mappings between a word form and multiple meanings/senses, the system develops a mechanism to deal with these inconsistencies to maintain comprehension at the word, sentence, and discourse levels. Previous research on homonym comprehension suggest that the system deals with these inconsistencies by initially activating all the meanings of the ambiguous word and then only maintaining activation of the appropriate meaning, or maintaining it to a higher level than the inappropriate meaning (e.g., Onifer & Swinney, 1981). Although this may be an accurate account for homonyms, this may not be the case for polysemes, because they can have highly related senses. For these words, the system may activate an underspecified representation of the polysemous word. Due to the greater overlap at the semantic level, an underspecified representation would be sufficient, initially, for comprehension. And, as context constrains the appropriate sense further, a more specified representation could be generated and maintained (Ferreira, Bailey, & Ferraro, 2002; Frazier & Rayner, 1990; Frisson & Pickering, 2001). Additionally, an initially underspecified representation may tax the system less than activating each and every specific code for each and every sense of a polyseme. Ambiguous words that fall in the middle of the continuum such as metaphors may activate multiple meanings/senses that are less specified than the specific meanings of homonyms. Alternatively, polysemous senses may all correspond to a core meaning (e.g., Nunberg, 1979), and that core meaning could provide enough activation to facilitate recognition and the system would not require selection of a specific sense. It is difficult to disentangle and test whether polyseme senses are connected to a core meaning or if they share features. It is possible that a set of features that are shared across all senses of a polysemous word could constitute a "core meaning." Future research will need to be done to develop methods to separate these constructs and to better understand polysemous word representation and processing.

Because they can simulate learning, PDP models such as the Settling Dynamics Account have the potential to account for how ambiguous word representation and processing change with learning. Experience- or instance-based models can similarly explain how these changes occur. Prior experience- or instance-based accounts posit that each encounter with a stimulus such as a word forms a memory trace (Hintzman, 1986; see also Reichle & Perfetti, 2003, for an instance-based model of morphological effects). The memory trace corresponds to the retrieval and encoding process of the experience. Thus, each exposure to a meaning or sense of an ambiguous word will form separate memory traces. Based on the prior assumptions in the semantic memory literature, we make the following assumptions and predictions. First, the level of semantic similarity between the multiple meanings of an ambiguous word will influence the ease with which the new meanings are acquired and retrieved, such that more semantically similar senses/meanings will be acquired and retrieved more easily than less semantically similar senses/meanings. This is because semantically related meanings will share several features and therefore will integrate more easily into the semantic network. Second, the level of semantic similarity between the multiple meanings of an ambiguous word will influence the semantic representation of the ambiguous word, such that words with related senses will share more semantic features than words with less related meanings. Third, meaning/sense frequencies will be established over time and be updated with each new experience with the word, such that a more recently encountered meaning/sense may become the dominant meaning/sense despite being a less frequently encountered meaning/sense in general. Fourth, more frequently encountered meanings/senses will be accessed more readily than less frequently encountered meanings/senses. Fifth, meaning frequency will interact with the level of semantic similarity between the multiple senses/meanings, such that meaning frequency will facilitate processing more for ambiguous words with less semantically similar meanings/senses. To further explain these predictions, we will discuss the differences in how polysemes and homonyms are learned, and how experience influences processing of ambiguous words.

As a learner is exposed to the different meanings of a homonym, the connections between the orthographic/phonological levels and each distinct semantic representation are established. More frequently experienced meanings would establish stronger connections from the form level to the specific semantic representation. Meaning frequencies can change with experience such that the initially dominant meaning could become the subordinate meaning. For example, the case or enclosure of a picture meaning of the word "frame" may initially be dominant for an individual, but the bowling meaning of "frame" might become dominant if the individual joins a bowling league. The learning of the multiple senses of a polysemous word would develop in a manner similar to homonym meanings, but it may be easier to integrate a semantically similar sense than a semantically dissimilar meaning into memory. In fact, Rodd et al. (2012) found that people learning new meanings for previously unambiguous words remembered more associations for words that had semantically similar meanings than words that had dissimilar meanings—possibly because they shared similar associations with the old meanings. It would be easier to integrate new senses that contain partially overlapping features with previously learned senses than it would be to learn new senses that that do not overlap with the existing senses. New meanings for previously known unambiguous words can also be established in real world settings, such as for the word 'Tweet' (i.e., send a message on Twitter). Therefore, instantiating an experience-based account would allow for a more dynamic explanation of semantic ambiguity resolution through development. An experience-based account could also make predictions for various levels of processing from word-level effects to discourse-level effects.

The activation for dominant versus subordinate meanings/senses may be fairly stable overall; however, at various levels of comprehension (e.g., sentence vs. discourse), meaning frequencies may be pushed in different directions. Providing ample context for the subordinate meaning of a homonym within a specific setting (e.g., reading a novel) may alter the meaning frequency or alternatively the influence frequency has on recognition, so that the subordinate meaning is more readily available. One might imagine reading a fantasy novel with knights and pages as the main characters. The word "page" in that context would refer to the subordinate sense, a nobleman's son training to become a knight. After reading for a longer period of time, with the subordinate sense instantiated more frequently, the system may activate the subordinate sense more strongly, thus switching dominance to facilitate comprehension. Perhaps after the reader has set down the book and the reader encounters the knight sense of "page" less and less frequently, the meaning frequencies will return to the average prior state.

Recent research by Rodd, Lopez Cutrin, Kirsch, Millar, and Davis (2013) supports this notion. Participants were more likely to generate associates for a primed meaning of a homonymous word despite the fact that the primed meaning was often associated with the subordinate sense. This study supports the idea that each encounter with the ambiguous word meaning changes the word's connection with each meaning, and that meaning dominance is flexible. However, it has yet to be determined how this effect would apply to polysemous word senses. We predict that polysemes would show a smaller dominance effect than homonyms. Therefore, although priming of the subordinate sense may increase activation of that specific sense, the unprimed senses share several features with the primed sense, which may eliminate short- or long-term priming effects.

The instantiation of an experience- or instance-based model or a PDP model, in conjunction with more recent evidence of the varying effects for different types of ambiguous words, has the potential to provide a greater understanding of semantic ambiguity resolution. This is because PDP and experience-based models that incorporate semantic similarity between the senses/meanings of ambiguous words allow for more specific predictions to be made for a wider range of ambiguous word types, and in a variety of situations from early word learning experiences to the processing of established meaning representations.

Conclusion

The past decade of research has advanced the understanding of ambiguity processing by examining and making comparisons between different types of ambiguous words. We now have a better understanding of the way different types of ambiguous words are processed and the important role that meaning similarity plays in ambiguity resolution. It is likely that early research that showed an ambiguous word advantage in processing actually reflected an advantage for polysemous and not homonymous words. Future research should take sense/meaning similarity into account, and consider this as a continuum rather than a dichotomy so that the entire range of meaning similarity can be explored. It is also important that ambiguity effects be examined across a range of tasks to explore the time course of processing, both in terms of the way that processing unfolds over time within a given task, and in terms of word learning with increased experience.

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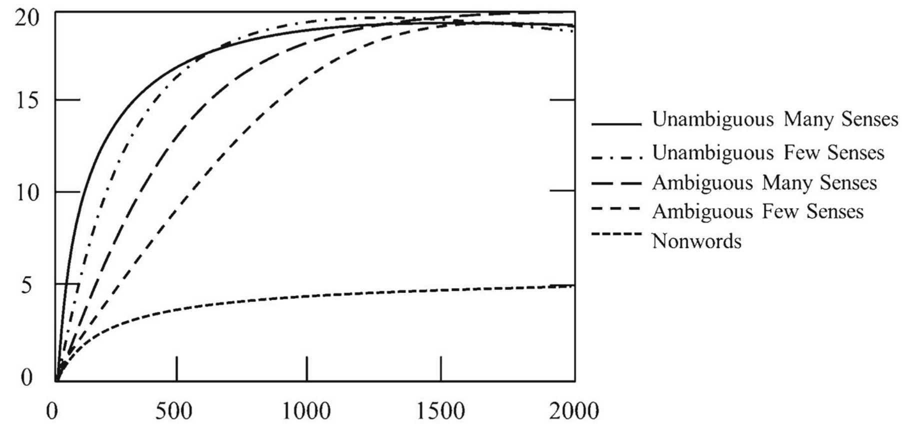

Fig. 1.

Activation of semantic units during settling (adapted from Rodd et al., 2004)

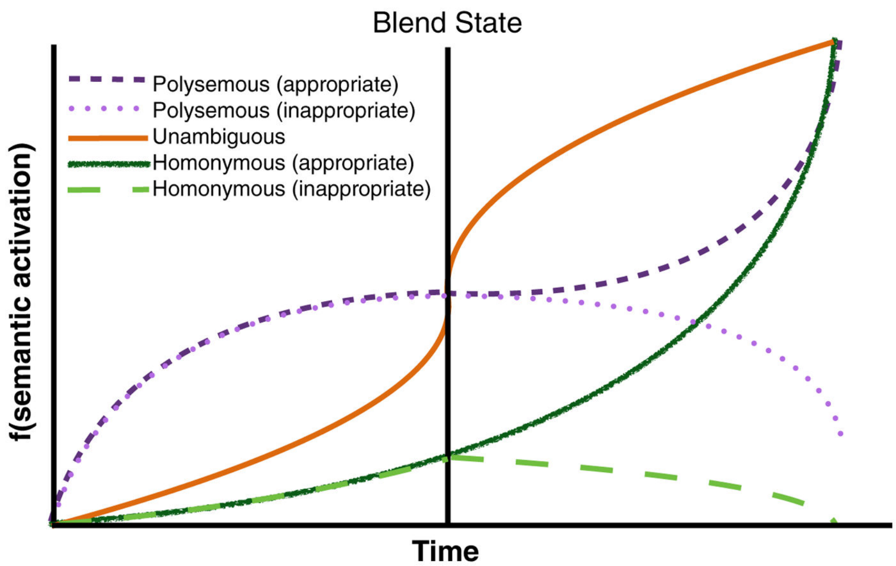

Fig. 2.
Settling Dynamics Account of Semantic Ambiguity (Armstrong, 2012)

Table 1

Summary of Reviewed Studies

Study	Words	Word classification	Task/language	Level of semantic engagement	Specifics	Findings	RT	Ambiguity effect
Armstrong and Plaut (2008)	P, H, U	Dictionary	Visual lexical decision in English	Medium	Manipulated non-word difficulty by increasing bigram frequency to enhance semantic processing. They had an easy non-word condition, medium non-word condition and hard non-word condition.	Polysemes were responded to faster than homonyms and unambiguous words in the easy and middle condition. Homonyms were responded to marginally more slowly than unambiguous words in the middle and hard conditions.	595–725	Polysemy advantage and homonym disadvantage
Armstrong and Plaut (2011)	P, H, U	Norms and dictionary	Visual lexical decision in English	Medium	Manipulated non-word difficulty (easy, medium, hard non-words) and stimulus quality (low contrast, high contrast)	The difficult non-word manipulation yielded a polysemy advantage. Low stimulus quality with the easy non-words yielded a marginal homonym disadvantage and significant polysemy advantage	518–719	Polysemy advantage and homonym disadvantage
Beretta et al. (2005)	P,H,U	Dictionary	Visual lexical decision in English	Low	MEG study using the same stimuli from Rodd et al. (2002, Experiment 2). They examined the M350 component.	They found a polysemy advantage and a homonym disadvantage in the behavioral RT. The MEG results showed that there were earlier mean peak M350 latencies for polysemous words compared to homonymous words.	611–648	Polysemy advantage and homonym disadvantage
Brown (2008)	P, H, U		Sense/nonsense in English	High	Participants made sense judgments on pairs of verb phrases that contained unambiguous verbs, ambiguous verbs, and polysemous verbs. The two phrases containing ambiguous verbs contained the consistent meaning/sense or the inconsistent meaning/sense.	Participants were faster and more accurate when the phrases had the same sense vs. a different sense verb. Homonym verb phrases yielded the slowest and least accurate responses. Polysemous verbs showed an accuracy and RT advantage over more distantly related verbs.	1056 – 1406	Polysemy advantage and homonym disadvantage
Foraker and Murphy (2012), Experiment 1	P, U	Dictionary	Self-paced reading in English	High	Compared reading times on critical sentences that related to the dominant or subordinate sense of a polysemous word after subjects read a sentence that related to the dominant sense, the subordinate sense or a neutral context.	Participants were faster to read sentences that biased the dominant sense.	1491–3083	
Foraker and Murphy (2012), Experiment 2	P, U	Dictionary	Self-paced reading in English	High	Same as Experiment 1, but they removed the sentence boundaries.	Participants were faster to read the disambiguating region when it corresponded to the dominant sense than the subordinate sense.	522–1027	
Foraker and Murphy (2012), Experiment 3	P, U	Dictionary	Eye-tracking in English	High	Same as Experiment 2	Longer reading times for subordinate senses in the neutral context condition. For second- pass measures (e.g., regressions) there was a	N/A Reading times	

Study	Words	Word classification	Task/language	Level of semantic engagement	Specifics	Findings	RT	Ambiguity effect
						marginal effect of dominance such that participants reread the sentence more often when the disambiguating region biased the subordinate sense.		
Hino et al. (2002), Experiment 2	U, A	Norms	Semantic categorization in English	High	Participants decided if a word belonged to the “alive” category.	Ambiguous words were responded to more slowly than unambiguous words.	707–737	Ambiguity disadvantage
Hino et al. (2006), Experiment 1	P, H, U	Norms	Lexical decision in Japanese	Low	Katakana Japanese words as non-words	Ambiguous words were responded to faster than unambiguous words but there was no difference between polysemous words with homonymous words and unambiguous words.	538–614	Ambiguity advantage
Hino et al. (2006), Experiment 2	P, H, U	Norms	Semantic categorization in Japanese	High	Participants decided if a word belonged to the “alive” category.	Ambiguous words were responded to more slowly than unambiguous words. Polysemous words were responded to more quickly and accurately than homonymous words.	665–768	Polysemy advantage
Hino et al. (2006), Experiment 3	P, H, U	Norms	Semantic categorization in Japanese	High	Participants decided if a word belonged to the “vegetable” category. This was considered a narrow category.	Neither an ambiguity disadvantage nor a polysemy advantage was found.	564–583	None
Hino et al. (2006), Experiment 4	P, H, U	Norms	Semantic categorization in Japanese	High	Participants decided if a word belonged to the “animal or vegetable” category.	Neither an ambiguity disadvantage nor a polysemy advantage was found.	542–565	None
Hino et al. (2006), Experiment 5	P, H, U	Norms	Semantic categorization in Japanese	High	Participants decided if a word belonged to the “job” category.	Ambiguous words were responded to more slowly than unambiguous words. Polysemous words were responded to more quickly than homonymous words.	636–668	Polysemy advantage
Hino et al. (2010), Experiment 1	U, A	Norms	Visual lexical decision in Japanese	Low	Katakana Japanese words as non-words	Ambiguous words were responded to faster than unambiguous words.	537–613	Ambiguity advantage
Hino et al. (2010), Experiment 2	P, H, U	Norms	Visual lexical decision in Japanese	Low	Kanji characters used as non-words to enhance semantic processing	Polysemous words were responded to faster than homonymous and unambiguous words.	544–664	Polysemy advantage
Hino et al. (2010), Experiment 3	P, H, U	Norms	Visual lexical decision in Japanese	Low	Kanji characters with related and unrelated meanings used as non-words to remove relatedness confound in Experiment 2	Ambiguous words were responded to faster than unambiguous words.	547–844	Ambiguity advantage
Klein and Murphy (2001), Experiment 1	P	Dictionary	Recognition in English	High	Participants studied phrases such as “liberal paper” and were asked to recall if they had studied the second word in a new phrase such as “wrapping paper” or the same	Participants recalled the more words in the same phrase condition than the same sense or different sense condition and participants recalled more words in the same sense	N/A accuracy only	

Study	Words	Word classification	Task/language	Level of semantic engagement	Specifics	Findings	RT	Ambiguity effect
					phrase. Phrases corresponded to the same or different sense.	condition than in the different sense condition.		
Klein and Murphy (2001), Experiment 2	P, H, U	Dictionary	Sense/nonsense in English	High	Participants made sense judgment on pairs of words that corresponded to the same or different sense.	Consistent-sense phrases were responded to faster and more accurately than inconsistent-sense pairs.	792–859	
Klein and Murphy (2001), Experiment 3	P, H, U	Dictionary	Sense/nonsense in English	High	Participants made sense judgment on pairs of words that corresponded to the same or different sense. Added homonyms to the stimulus list.	Consistent-sense phrases were responded to faster and more accurately than inconsistent-sense pairs. The size of the consistency effect was similar for polysemes and homonyms.	774–850	
Klein and Murphy (2001), Experiment 4	P, H, U	Dictionary	Lexical decision in English	Low	Explored whether effects were due to the modifying word; phrases wrapping paper and shredded paper, wrapping may have primed shredded.	Homonym modifiers were responded to faster and more accurately than polyseme modifiers in the analysis by subjects.	565–593	
Klein and Murphy (2001), Experiment 5	P, H, U	Dictionary	Sense/nonsense in English	High	Participants made sense judgment on pairs of words that corresponded to the same, different sense or neutral sense (blank line).	Fastest and most accurate responses for the consistent condition; slowest and least accurate responses for the inconsistent condition; neutral condition fell in between.	832–938	
Klepousniotou (2002)	P, H	Published norms; selected based on linguistic principles	Primed lexical decision in English	Medium	Examined different types of ambiguous words including metonyms, metaphors, name, and homonyms.	Participants responded faster and had a larger priming effect for the metonymous words (e.g., chicken animal/chicken food) than the homonymous words.	511–634	Polysemy advantage
Klepousniotou and Baum (2007), Experiment 1	P, H, U	Published norms and selected based on linguistic principles	Auditory lexical decision in English	Low	Metaphorical and metonymous non-words and pronounceable non-words	Both types of polysemous words yielded faster RT than homonyms and unambiguous words.	908–1024	Polysemy advantage
Klepousniotou and Baum (2007), Experiment 2	P, H, U	Published norms; selected based on linguistic principles	Visual lexical decision in English	Low	Metaphorical and metonymous non-words and pronounceable non-words	Metonymous polysemous words were responded to faster than metaphorical polysemous, homonymous, and unambiguous words.	541–566	Polysemy advantage
Klepousniotou et al. (2008)	P, H, U		Sense/nonsense in English	High	Same as Klein and Murphy (2001), Experiments 2 and 3. Neutral context used a line of asterisks instead of a blank line. They examined ambiguous words with low overlapping senses, high overlapping senses, medium overlapping senses.	Participants were faster to make sense judgments to polysemous word pairs with highly overlapping senses than ambiguous words with moderate to low overlapping senses.	768–937	Polysemy advantage

Study	Words	Word classification	Task/language	Level of semantic engagement	Specifics	Findings	RT	Ambiguity effect
Klepousniotou et al. (2012)	P,H,U	Published norms; selected based on linguistic principles	Primed lexical decision in English	High	ERP study. Metaphorical, metonymous and balanced and unbalanced homonymous words.	Greater N400 reduction (priming effect) for dominant primes of unbalanced homonyms than subordinate primes. Larger N400 reduction for Subordinate and dominant primes of balanced homonyms and metonymical polysemes than unrelated controls.	N/A Delayed Task	
Lin and Ahrens (2010)	H, U	Norms	Visual lexical decision in Mandarin Chinese	Low	Metaphorical words and homonymous ambiguous words	Homonyms were responded to faster than unambiguous words.	549–577	Ambiguity advantage
Pexman et al. (2004) Experiment 1	U, A	Norms	Visual lexical decision in English	Low	High and low frequency ambiguous and unambiguous words and pronounceable non-words	Low frequency ambiguous words were responded to faster than unambiguous words. High frequency ambiguous words showed no RT advantage in lexical decision.	511–609	Ambiguity advantage for low frequency words
Pexman et al. (2004), Experiment 2	U, A	Norms	Relatedness judgment in English	High	Half of the critical words were paired with related words and half with unrelated words.	Ambiguous words were responded to more slowly than unambiguous words on the related trials but not on unrelated trials. A positive correlation between relatedness of meanings and RT was found only for related trials.	770–960	Polysemy advantage
Pexman et al. (2004), Experiment 3	U, A	Norms	Relatedness judgment in English	High	Half of the critical words were paired with related words and half with unrelated words. They paired half of the words with the dominant sense and half with the subordinate sense.	No ambiguity disadvantage found on the unrelated trials, regardless of whether the word was paired with a word related to its dominant or subordinate sense.	812–962	
Pexman et al. (2004), Experiment 4	P, H, U	Norms	Visual lexical decision in Japanese	Low	Katakana Japanese words as non-words	Polysemous and homonymous words were responded to more quickly than unambiguous words.	547–578	Ambiguity advantage
Pexman et al. (2004), Experiment 5	P, H, U	Norms	Relatedness judgment in Japanese	High		An ambiguity disadvantage was found only on related trials but not on unrelated trials. A polysemy advantage was found on the related trials but not on the unrelated trials.	643–748	Polysemy advantage
Pylkkänen et al. (2006)	P,H,U	Dictionary	Sense/nonsense in English	High	In an MEG study participants made sense judgments on pairs of words that corresponded to the same or different sense. M350 component was examined.	The behavioral data revealed the same results as Klein and Murphy (2001, Experiment 2). MEG results revealed earlier mean peak M350 latencies for related polysemous pairs than unrelated pairs, but found later mean peak M350 latencies for related homonymous pairs than unrelated pairs.	660–765	

Study	Words	Word classification	Task/language	Level of semantic engagement	Specifics	Findings	RT	Ambiguity effect
Rodd et al. (2002), Experiment 1	P,H,U	Dictionary	Visual lexical decision in English	Low	Non-word were pseudohomophones	Words with many senses were responded to faster than words with few senses	556–636	Polysemy advantage
Rodd et al. (2002), Experiment 2	P,H,U	Dictionary	Visual lexical decision in English	Low	Non-words were pseudohomophones	Words with many senses were responded to faster than words with few senses	567–587	Polysemy advantage
Rodd et al. (2002), Experiment 3	P,H,U	Dictionary	Auditory lexical decision in English	Low	Pronounceable non-words	Words with many senses were responded to faster than words with fewer senses and words with more than one meaning were responded to more slowly than words with a single meaning	924–986	Polysemy advantage and homonym disadvantage
Rodd et al. (2012), Experiment 1	P, H, U	N/A	Recall in English	High	Trained participants new meanings to previously known unambiguous words using incidental word learning.	Participants remembered more related word meanings than unrelated word meanings.	N/A accuracy only	Polysemy advantage
Rodd et al. (2012), Experiment 2	P, H, U	N/A	Recall and visual lexical decision in English	Low	Trained participants new meanings to previously known unambiguous words using incidental word learning.	Participants recalled more vocabulary words with related meanings than unrelated meanings. Participants were faster to make lexical decisions on trained words than untrained words.	590–620	Polysemy advantage
Rodd et al. (2012), Experiment 3	P, H, U	N/A	Recall and visual lexical decision in English	Low	Trained participants new meanings to previously known unambiguous words using explicit and semantic based training	The vocabulary training that used explicit and semantic based methods yielded higher recall accuracy than in Exp. 1 and 2. Participants made faster lexical decisions on trained related words than trained unrelated words.	560–605	Polysemy advantage

P polysemous, *H* homonymous, *U* unambiguous, *A* ambiguous