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The Influence of Syntactic Category and Semantic Constraints on Lexical Ambiguity Resolution: An Eye Movement Study of Processing Chinese Homographs*

Po-Heng Chen and Jie-Li Tsai

National Chengchi University

The purpose of the present study is twofold: (1) To examine whether the syntactic category constraint can determine the semantic resolution of Chinese syntactic category ambiguous words; and (2) to investigate whether the syntactic category of alternative meanings of Chinese homographs can influence the subordinate bias effect (SBE) during lexical ambiguity resolution. In the present study, four types of Chinese biased homographs (NN, VV, VN, and NV) were embedded into syntactically and semantically subordinate-biased sentences. Each homograph was assigned a frequency-matched unambiguous word as control, which could fit into the same sentence frame. Participants' eye movements were recorded as they read each sentence. In general, the results showed that in a subordinate-biased context, (1) the SBE for the four types of homograph was significant only in the second-pass reading on the post-target words and (2) numerically, the NV homographs revealed a larger effect size of SBE than VN homographs on both target and post-target words. Our findings support the constraint-satisfaction models, suggesting that the syntactic category constraint is not the only factor influencing the semantic resolution of syntactic category ambiguous words, which is opposed to the prediction of the syntax-first models.

Key words: lexical ambiguity resolution, subordinate bias effect, syntactic category ambiguity

1. Introduction

Over the past three decades, lexical ambiguity resolution has been one of the hot issues in psycholinguistics and neurolinguistics. Researchers have been interested in whether one or multiple meanings are activated when an ambiguous word is processed. Many studies have shown that meaning dominance (i.e. frequency of use) may influence the activation level of alternative meanings of a homograph. The dominant meaning (i.e. high-frequency meaning) reaches a high activation level more easily than the subordinate meaning (i.e. low-frequency meaning) (Burgess & Simpson 1988; Hogaboam & Perfetti 1975; Simpson 1981; Simpson & Burgess 1985). When the alternative meanings are equally frequent, they reach a high activation level simultaneously and compete with each other (Duffy et al. 1988; Rayner & Duffy 1986; Seidenberg et al. 1982; Sereno et al. 1992).

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However, meaning dominance may interact with contexts during lexical ambiguity resolution. Several eye-movement studies have consistently found the subordinate bias effect (SBE) for biased homographs (i.e. the frequency of alternative meanings is not equal) (Duffy et al. 1988, 2001; Lu 2012; Pacht & Rayner 1993; Rayner & Duffy 1986; Rayner & Frazier 1989; Rayner et al. 1994), indicating that a subordinate-biased context can boost the activation of the subordinate meaning and causes meaning competition. In addition, syntactic category can affect word ambiguity resolution. Pickering & Frisson (2001) conducted an eye-movement study and found the SBE on fixation times for biased homographic nouns but not for biased homographic verbs. Their results suggested that the resolution of biased homographic verbs was delayed.

In addition to homographic nouns and verbs, there is another type of homograph with ambiguous syntactic categories (e.g. *watch* in English). A syntactic category ambiguous (SCA) word serves as a means of examining not only the syntactic category of homographs, but also the function of syntactic category constraint on lexical ambiguity resolution. Folk & Morris (2003) observed the absence of the subordinate-biased effect for SCA homographs in semantically and syntactically subordinate-biased sentential context. The finding implied that syntactic category constraint can mediate semantic ambiguity resolution. This result can fit into the syntax-first models, in which the analysis of syntactic information is assumed to precede the analysis of semantic information. However, an alternative explanation of the absence of the SBE for SCA words is that the inherent difficulty of verb meaning limits the speed of activation and delays the meaning competition. In the present study, we simultaneously manipulated four types of homograph based on the syntactic categories of the dominant and subordinate meanings. Using the subordinate-biased context, our study aims to examine whether syntactic category of homographs and contextual constraints can affect Chinese semantic ambiguity resolution and thus provide the evidence for validating different sentence-processing models.

1.1 Sentence-processing models

The primary task of comprehending a sentence is to integrate plenty of information from different sources (e.g. syntactic structure, word semantics, real-world experience, etc.). Some researchers have debated how syntactic and semantic information interact during sentence comprehension. With different assumptions, two primary classes of model have been proposed: syntax-first models and constraint-satisfaction models.

1.1.1 Syntax-first models

The most influential model of syntax-first accounts is the garden-path model (Frazier 1979, 1987, 1989; Frazier & Rayner 1982; Rayner et al. 1983), which was originally proposed to explain the resolution of syntactic ambiguity. In this model, sentence comprehension is assumed to engage two serial processing stages. At the first stage, sentence comprehension relies on construction of the simplest sentence structure, which is based on the syntactic category information. More

importantly, the mechanism of syntactic processing is modular, impervious to non-syntactic contextual information (e.g. lexical-semantic, pragmatic information). Therefore, the language processor considers only the available structural information to generate a single candidate structure. At the second stage, non-syntactic information is taken into consideration. If the initial candidate structure turns out to be inconsistent with non-syntactic information that is processed during the second stage, reanalysis occurs and leads to processing difficulty.

Rayner et al. (1983) conducted an eye-tracking experiment and supported the idea that semantic and pragmatic information cannot influence the initial syntactic analysis during sentence comprehension. In their experiment, they manipulated the relative likelihood of possible real-world events (i.e. the plausibility of sentences) and the appearance of a relative pronoun, constructing four types of sentence: (1) reduced implausible: {*The dealer sold the car wasn't sure that it was safe.*}; (2) reduced plausible: {*The teenager sold the car wasn't sure that it was safe.*}; (3) unreduced plausible: {*The teenager who was sold the car wasn't sure that it was safe.*}; and (4) active implausible: {*The teenager sold the car but wasn't sure that it was safe.*}. In terms of the total reading time (per character) for the whole sentence, they found no differences between the reduced implausible and the reduced plausible sentences, while both types of reduced sentence were read for longer than were the unreduced plausible and active implausible sentences. In addition, the reading times for the unreduced plausible sentence were longer than those for the active implausible sentences. They further discovered that the longer reading times for both types of reduced sentence resulted from their longer reading times in the disambiguating region (e.g. *wasn't sure that it was safe*), which indicated that readers initially constructed the simplest structure (i.e. the active sentence structure) and encountered processing difficulty when realizing the sentence was a reduced relative-clause sentence. Further, the absence of increased reading times on the implausible sentences suggested that the plausibility did not influence the initial syntactic analysis. In sum, the study of Rayner et al. (1983) supported the idea that during sentence comprehension the initial syntactic analysis was independent and impervious to semantic analysis.

More recently, Friederici et al. (1996) and Friederici (1995, 2002) also proposed a neurocognitive model of sentence processing on the basis of electrophysiological data. In this model, three phases are proposed to specify the time course of syntactic and semantic processes. During phase 1, syntactic structure is constructed based on syntactic category information. Violation of syntactic category information usually elicits an early left-anterior negativity (ELAN) around 100–300 ms after target word onset (Friederici et al. 1993; Hahne & Friederici 1999; Hahne & Jescheniak 2001). During phase 2, morphosyntactic and semantic information is processed. Words that are semantically inconsistent with the prior context usually elicit a larger negative brain potential (N400) (300–500 ms), peaking around 400 ms (Kutas & Federmeier 2000; Kutas & Hillyard 1984; Neville et al. 1991). Finally, phase 3 represents integration and reanalysis of various types of information. Both syntactically anomalous and garden-path sentences usually elicit a positive brain potential (P600), peaking around 600 ms (Hagoort et al. 1993; Osterhout & Holcomb 1992; Osterhout et al. 1994). Interestingly, when a word violates both syntactic category and semantic constraints in a sentence, only an ELAN appears and no N400 (Friederici et al. 1999). This finding supports syntax-first models, in which syntactic analysis is assumed to precede semantic analysis.

1.1.2 Constraint-satisfaction models

An alternative class of model, constraint-satisfaction models, was proposed in the 1990s to challenge syntax-first models (Macdonald 1993; Macdonald & Seidenberg 2006; Macdonald et al. 1994; Trueswell & Tanenhaus 1994; Trueswell et al. 1993, 1994). According to constraint-satisfaction models, two stages of sentence comprehension are unnecessary. Sentence processing engages one mechanism, in which all sources of information are available to interact among one another. Non-syntactic constraints need not wait until a second stage to influence ambiguity resolution. One of the important assumptions in constraint-satisfaction models is that multiple candidates are activated initially and weighted by probabilistic constraints (e.g. frequency, plausibility, etc.). When the probabilistic constraints are strongly consistent with one analysis, processing is easy because no selection is needed. In contrast, when multiple analyses are equally supported by constraints, processing difficulty occurs due to the competition between multiple candidates.

Trueswell et al. (1994) conducted an eye-movement experiment and suggested that the lexical-semantic information (e.g. thematic-role) can be used by readers immediately during comprehension of relative clauses. They manipulated the animacy of noun (animate versus inanimate), the relative clause type (reduced versus unreduced), and the type of verb within the relative clause (ambiguous: regular verb versus unambiguous: irregular verb). For animate nouns, they found longer first-pass reading times for reduced-relative clauses in the disambiguating region and longer second-pass reading times in both the verb and the disambiguating regions. These results indicated that readers began to encounter processing difficulty because they mistook the verb as a main verb initially. For inanimate nouns, neither first-pass nor second-pass reading times showed significant differences between reduced- and unreduced-relative clauses in any region. Thus, there seemed to be no processing difficulty with the inanimate nouns. Nevertheless, the authors discovered that their inanimate stimuli varied in patient-typicality (i.e. whether the noun is a good patient or theme with regard to the verb following). For example, their norming data of patient-typicality indicated *the textbook–loved* pair obtained a low score, resulting in weak semantic fit, while *the evidence–examined* pair received a high score, resulting in strong semantic fit. Further analyses of first-pass reading times revealed that the lack of processing difficulty remained only in the case of strong semantic fit. In the case of weak semantic fit, reduced-relative clauses required longer first-pass reading times than did unreduced ones in both the verb and the disambiguating regions. Therefore, the study of Trueswell et al. (1994) suggested the influence of semantic information in an early stage of sentence comprehension.

In sum, two primary models of sentence processing have been proposed to elucidate how syntactic and semantic information interact during sentence comprehension. Nevertheless, most evidence comes from the findings of syntactic ambiguity resolution. It remains unclear whether these sentence-processing models can explain the resolution of lexical ambiguity. In the next section, some crucial issues and findings relating to lexical ambiguity resolution are reviewed first, and then some implications of distinct sentence-processing models for lexical ambiguity resolution are put forward.

1.2 Issues of lexical ambiguity resolution

Over the past three decades, psycholinguists and neurolinguists have been interested in lexical ambiguity resolution by using various methodologies, such as cross-modal priming, eye-tracking

and event-related potential (ERP) methods. A primary issue concerns whether multiple meanings of an ambiguous word are activated at the same time. Previous research has demonstrated that meaning dominance, syntactic category, and contextual constraints have an impact on semantic resolution of ambiguous words.

1.2.1 Meaning dominance

Meaning dominance was defined as the relative frequency of usage of alternative meanings involved in an ambiguous word. It can be assessed by using the free-association technique, in which subjects write down the first meaning that came to mind when given the ambiguous word in isolation (Gawlick-Grendell & Woltz 1994; Hogaboam & Perfetti 1975). Based on meaning dominance, two types of homograph can be differentiated: *balanced homographs* and *biased homographs*. Balanced homographs have multiple meanings whose frequencies of usage are equal, while biased homographs have one dominant (high-frequency) meaning and other subordinate (low-frequency) meanings.

Previous research has demonstrated that meaning dominance would influence the activations of alternative meanings of homographs (Carpenter & Daneman 1981; Duffy et al. 1988; Rayner & Duffy 1986). In a neutral context (i.e. a context where no disambiguating information is provided), the alternative meanings of a balanced homograph were activated simultaneously (Rayner & Duffy 1986; Swinney 1979), while the dominant meaning of a biased homograph was retrieved prior to the subordinate meaning (Hogaboam & Perfetti 1975; Simpson 1981). Swinney (1979) investigated the semantic resolution of balanced homographs by using a cross-modal priming paradigm with a lexical decision task. In the cross-modal priming paradigm, subjects listened to sentences containing lexical ambiguities (e.g. *bugs*) followed by a visually presented target (e.g. contextually appropriate: *ant*; contextually inappropriate: *spy*; unrelated: *sew*). Their task was to determine whether the visually presented target formed a word or not. The results demonstrated facilitated lexical decisions for the visual targets immediately following the end of the homographs, no matter whether the target was related to the contextually intended meaning or the contextually unintended meaning of the ambiguity. Also using the lexical decision task, Simpson (1981) examined meaning activation of biased homographs in Experiment 1 by presenting the homographs in isolation (e.g. *bank*), which were immediately followed by two types of target word (e.g. dominant-related: *money*; subordinate-related: *river*). In addition to the prime-target related pairs, prime-target unrelated pairs (e.g. prime: *calf*; dominant-unrelated targets: *money*; subordinate-unrelated target: *river*) were used as controls. Compared to the unrelated controls, only when the target word was related to the dominant meaning was the lexical decision latency facilitated. This study supported the ordered access model of lexical ambiguity resolution (Hogaboam & Perfetti 1975), suggesting that biased homographs were resolved on the basis of the relative frequency of the meanings when there was no disambiguating context. The retrieval of the dominant meaning was faster than that of the subordinate meaning.

1.2.2 Syntactic category

Words from different syntactic categories are linguistically, psychologically, and neurologically distinct. It may take more effort to process verbs than to process nouns in terms of semantics,

syntax, and morphology (for a review, see Vigliocco et al. 2011). Some empirical studies also provided evidence that processing verbs is more demanding than processing nouns (Rayner 1977; J. A. Sereno 1999; Vigliocco et al. 2004). For example, J. A. Sereno (1999) presented nouns and verbs with either high or low frequency to either the left or the right visual field in a noun/verb categorization task and a lexical decision task. In both tasks, responses to nouns were significantly faster than those to verbs. In addition, from the perspective of language acquisition, the evidence that verbs are acquired later than nouns may reflect the psychological complexity of verbs (Gentner 1982, 2006). Therefore, it is reasonable to consider more difficulties for processing verbs than nouns during sentence comprehension.

In fact, the greater difficulties of processing verbs compared to nouns also influence the resolution of ambiguous words. Pickering & Frisson (2001) conducted eye-tracking experiments to investigate the processing of verbs, including verbs with multiple meanings (homographs), verbs with multiple senses (polysemy), and unambiguous verbs. The two types of ambiguous verb were biased in terms of the frequencies of alternative interpretations. They manipulated whether preceding context or succeeding context contained disambiguating information, and whether dominant or subordinate interpretation was supported by the disambiguating information. For the homographic verbs, they found no context and meaning frequency effects in the measures of initial processing (i.e. first-pass time and first-pass regressions) in the verb region; instead, in the region immediately following the verbs, the context effects were observed on first-pass time, and the meaning frequency effects emerged on both total time and second-pass time. Thus, they suggested that the resolution of homographic verbs was delayed in comparison with that of homographic nouns, since the SBE was not observed in the verb region but in the following region. The delayed resolution allowed alternative meanings of homographic verbs to reach a high level of activation. As a result, the meaning frequency effects did not occur immediately in the verb region.

In addition to ambiguous verbs, another type of homograph involving a verb meaning is syntactic category ambiguous words (SCA words), whose multiple meanings cross different syntactic categories (e.g. *watch*). People may encounter syntactic category ambiguities when there are SCA words in the sentences. Previous literature on the resolution of syntactic category ambiguities yielded different findings. Frazier & Rayner (1987) found that (a) reading times for the ambiguous word phrase (e.g. *desert trains*) were longer when preceded by a disambiguating determiner (e.g. *I know that <u>this</u> desert trains young people to be especially tough.*) compared to when preceded by a non-disambiguating determiner (e.g. *I know that <u>the</u> desert trains young people to be especially tough.*); and (b) reading times for the remainder of the sentence, containing disambiguating information, showed an opposite pattern. To account for these findings, they proposed a delay model: When no disambiguating information is provided prior to a syntactic category ambiguity, the resolution will be delayed until helpful information is encountered, regardless of interpretation preference of the ambiguity itself.

Some studies, however, supported immediate resolution of syntactic category ambiguity (Gibson 2006; Jones et al. 2012; Macdonald 1993). For example, Jones et al. (2012) conducted eye-movement experiments to investigate how biased SCA words are resolved in disambiguating or neutral contexts. In Experiment 1, preceding context provided syntactic category information consistent with either the dominant or the subordinate meaning of SCA words (e.g. *I was shocked to see him <u>counter</u> the offer so quickly.*). The results showed no ambiguity effects (ambiguity > unambiguous controls) in

gaze-duration measures whenever the prior context was biased toward the dominant or subordinate meaning, indicating that the syntactically appropriate meaning was initially selected. However, the ambiguity effects indeed emerged in later eye-movement measures, such as regression-out probability from target words and second-pass time on prior disambiguating context, only when the subordinate meaning was biased. These processing costs suggested that readers had difficulty in integrating the subordinate meaning due to activation of the dominant meaning. In Experiment 2, preceding context was neutral and disambiguating information was provided in post-target region (e.g. *We watched her duck eat all of the bread.*). The results showed ambiguity effects in different measures consistently in the subordinate-biased condition, including gaze duration on target words, regression-out probability from post-target regions, second-pass time on target words, and second-pass time in post-target regions. The ambiguity effects indicated processing costs of the inconsistency between the initially selected (dominant) meaning and the context-intended (subordinate) meaning. Taken together, their findings suggested that readers immediately select one meaning for SCA words and refuted the delay model proposed by Frazier & Rayner (1987).

To sum up, it is questionable whether syntactic category ambiguity is resolved by a unique delay mechanism. The delay model was proposed on the basis of the delayed resolution observed on balanced SCA words in neutral contexts. However, the investigation of biased SCA words in disambiguating and in neutral contexts did not support the delay model. This indicates that the resolution of syntactic category ambiguity is not always delayed. Instead, like lexical-semantic ambiguity resolution, the probabilistic constraints matter. Previous research has demonstrated the influence of syntactic category of meanings on lexical ambiguity resolution. Presumably, the inherent processing difficulty of verb meanings would delay the semantic resolution of SCA words. Therefore, it is of importance to distinguish homographic nouns, homographic verbs, and SCA words when examining lexical ambiguity resolution.

1.2.3 Contextual constraints

1.2.3.1 Semantic constraint

Hitherto, the focus has been more on the lexical nature of ambiguous words. However, more often than not, people resolve lexical ambiguity in sentences rather than in isolation. Thus, of great significance is whether sentential contexts could influence the resolution of lexical ambiguity. If any, would different types of context exert distinct influence on the resolution of ambiguous words? Most literature has attended to the influence of semantic context. For balanced homographs, prior semantic information seemed effective in constraining meaning activation of the homographs, resulting in selective access (Schvaneveldt et al. 1976). For biased homographs, more mixed results have been shown in previous studies. Some research supported the selective access view, that is, contextual information has an early impact on the activation of lexical meaning (Glucksberg et al. 1986; Schvaneveldt et al. 1976; Simpson 1981; Simpson & Krueger 1991; Tabossi 1988; Tabossi et al. 1987; Tabossi & Zardon 1993). Other studies bolstered the exhaustive access view, in which the meaning activation is assumed to be encapsulated in a modular system, and contextual information helps select an appropriate meaning at post-lexical stage (Onifer & Swinney 1981; Seidenberg

et al. 1982; Swaab et al. 2003; Swinney 1979; Tanenhaus & Donnenwerth-Nolan 1984; Tanenhaus et al. 1979).

Recent eye-movement studies on lexical ambiguity resolution have clearly depicted the interaction between meaning dominance and semantic contextual influence (Duffy et al. 1988; Rayner & Duffy 1986). For instance, Duffy et al. (1988) manipulated ambiguity types (balanced versus biased homographs) and disambiguating locations (pre-target versus post-target disambiguation) in a normal reading experiment. Each homograph was paired with a frequency- and length-matched unambiguous control word, which could fit smoothly into the same sentence as the corresponding homograph. The results showed that gaze durations on the balanced homographs were longer than those on biased homographs or on the control words when preceding context contained no disambiguating information. This ambiguity effect was presumably due to the competition of multiple meanings of the balanced homographs. In addition, when preceding context contained disambiguating information toward the subordinate meaning of the biased homographs, readers fixated longer on the biased homographs than on the balanced homographs or on the control words. This SBE effect demonstrated the interaction between meaning dominance and semantic contextual information (Rayner et al. 1994). Furthermore, there was no significant difference between the gaze durations on the balanced homographs and on the control words in the biasing context.

The SBE was robust and consistently found in many eye-movement studies (Duffy et al. 1988, 2001; Lu 2012; Pacht & Rayner 1993; Rayner & Duffy 1986; Rayner & Frazier 1989; Rayner et al. 1994). In order to explicate the SBE, the reordered access model (Duffy et al. 1988, 2001) was proposed to highlight the early influence of semantic context. In neutral contexts, meaning dominance can mediate the resolution of lexical ambiguity. On the other hand, in biasing contexts, the semantic information can boost the activation level of the context-intended meaning. As a result, for balanced homographs, the intended meaning has a higher level of activation and becomes available earlier than the unintended one, resulting in the absence of meaning competition. For biased homographs, context and meaning dominance jointly determine the availability of alternative meanings. In dominant-biased contexts, only the dominant meaning reaches a high level of activation due to support from both context and meaning frequency. In the subordinate-biased contexts, access to the subordinate meaning is speeded up with the help of context, while the dominant meaning still reaches a high level of activation. Thus, the alternative meanings compete with each other. To sum up, the reordered access model allows the interaction between semantic contexts and meaning dominance to influence initial access of meaning.

1.2.3.2 Syntactic constraint

In addition to semantic context, syntactic context is also important to word processing in sentences (Marslen-Wilson & Tyler 1980; Tyler & Warren 1987; West & Stanovich 1986; Wright & Garrett 1984). Syntactic category ambiguity provides an opportunity for investigating the influence of prior syntactic constraints on lexical ambiguity resolution. The key issue is whether leading syntactic category constraints can mediate semantic resolution of syntactic category ambiguities. Previous research has shown discrepant results. Some psycholinguistic and electrophysiological studies demonstrated that syntactic category information alone cannot exclusively select the context-intended meaning of SCA words (Federmeier et al. 2000; Lee & Federmeier 2006, 2009; Seidenberg

et al. 1982; Tanenhaus et al. 1979). For example, Lee & Federmeier (2009) examined the effects of syntactic and semantic context on ambiguity resolution for noun–verb homographs, using the ERP methodology. In Experiment 1, they manipulated two variables, word types (NV-homographs versus unambiguous words) and sentential context types (congruent versus syntactic prose). Congruent sentences provided syntactic category and semantic information (e.g. *He said the long, graceful bird was called a swallow.*), while syntactic prose sentences provided only syntactic category information but incoherent semantic information (e.g. *He realized the young, English life was assigned a swallow.*). They found that a sustained frontal negativity (200–700 ms) was elicited by the NV-homographs in the syntactic prose sentences. However, the sustained frontal negativity was largely reduced when additional semantic information was available in contexts, namely, the congruent sentences. In addition, N400 elicited by the NV-homographs was still more negative than that elicited by unambiguous words in the congruent condition. Furthermore, in Experiment 2, they found that NV-homographs elicited a larger N400 than did unambiguous words only when context was biased toward the subordinate meaning of homographs. To sum up, their results suggested that semantic information is also important to the semantic resolution of SCA words, and that the activation of the dominant meaning of NV-homographs is automatic and cannot be prevented by the subordinate-biased contexts.

In contrast, some recent eye-movement studies buttressed the view that syntactic category information can guide meaning resolution of SCA words (Folk & Morris 2003; Jones et al. 2012). For example, in Experiment 1, Folk & Morris (2003) embedded biased noun–noun and noun–verb homographs into sentences which were both semantically and syntactically biased toward either the dominant or the subordinate meaning of the homographs. They observed longer gaze durations and second-pass times on the noun–noun homographs compared to the unambiguous control words, only when preceding context instantiated the subordinate meaning. This ambiguity effect was also shown in the post-target region, namely, spillover times. However, for noun–verb homographs, no matter when prior context instantiated the dominant or subordinate meaning, the ambiguity effect was found only on spillover times and second-pass times, but not on gaze durations.

In Experiment 2, Folk & Morris (2003) further examined the influence of syntactic category constraints alone on the meaning resolution of SCA words. Unlike in Experiment 1, balanced noun–noun and noun–verb homographs were embedded into sentences that were semantically neutral but syntactically biased toward the noun meaning of the homographs. Semantically disambiguating information was provided in the succeeding context. The results showed longer gaze durations on noun–noun homographs and quasi-first-pass times (go-past times) in the disambiguating regions compared to the unambiguous control words. However, the ambiguity effect did not occur on spillover times. For noun–verb homographs, no processing difficulty was found in any measure, indicating that the context-intended meaning was initially selected with the help of syntactic category constraints.

Taken together, Folk & Morris's experiments replicated the SBE for noun–noun homographs; in contrast, there was non-significant SBE for noun–verb homographs. Thus, they suggested that syntactic category information can mediate the meaning resolution of SCA words, as aligned with a syntax-first account of sentence processing.

Nevertheless, it remains unclear whether the SBE would be absent when prior context instantiates a subordinate verb meaning of SCA words, since the sentence context was always consistent with the noun interpretation in Folk & Morris's study. In addition, the results of Folk & Morris's study

may not completely support the syntax-first account, since the SBE still occurred in second-pass times and in the post-target region for SCA words, suggesting a delay of meaning competition. As suggested by Pickering & Frisson (2001), a verb meaning may need more time to access and reach a high level of activation than a noun meaning. As a result, meaning competition between the alternative meanings of SCA words might be delayed. The absence of the SBE observed by Folk & Morris may simply be due to the processing difficulty of a verb meaning.

In summary, it is still controversial whether syntactic category information can determine the meaning resolution of syntactic category ambiguity. Although some research has demonstrated that lexical-semantic ambiguity and syntactic category ambiguity might not be resolved in the same way, different combinations of meaning dominance and syntactic category are not taken into consideration. As a result, the present study attempts to clarify the influence of syntactic category and semantic constraints on the resolution of Chinese lexical-semantic and syntactic category ambiguities.

1.3 Processing of Chinese ambiguous words

With different types of ambiguous word and experimental paradigm, studies on Chinese lexical ambiguity resolution have also obtained discrepant results. The meaning relateness and meaning dominance are responsible for different effects which support the view of selective or multiple access for word meanings (Chen 2009; Han et al. 2009; Lu 2012; Ren et al. 2008; C. Yang 2010; Zhou & Chen 2006). Similar to English findings, meaning dominance and contextual bias jointly influence Chinese lexical ambiguity resolution (Han et al. 2009; Lu 2012; Ren et al. 2008; Yang 2010). In a biasing context, the SBE was also observed for Chinese biased homographs. For example, using a normal reading task and a spoken sentence comprehension task with visual world paradigm, Lu (2012) conducted two eye-tracking experiments to investigate how Chinese biased homographs are resolved in a subordinate-biased context. In her Experiment 1, three types of target word were manipulated: low-frequency homographs (A), low-frequency unambiguous words (LF), and high-frequency homographs (HF). The results showed a significant SBE (A > LF) in gaze durations, and second-pass times on the target as well as in go-past time and rereading probability in the post-target region. In her Experiment 2, the time course of Chinese lexical ambiguity resolution was examined. The results showed that both the dominant and the subordinate meanings of homographs were activated prior to the utterance of the following word. Taken together, the two experiments demonstrated that the dominant meaning was still activated even in a subordinate-biased context, supporting the reordered access model. Finally, the resolution of Chinese ambiguous verbs was also delayed. Han et al. (2009) observed a delayed SBE for Chinese biased homographic verbs in a subordinate-biased context. The SBE was delayed until the second-pass reading on the disambiguating information following the target.

The resolution of syntactic category ambiguity for Chinese is not well documented. In a self-paced experiment involving reading of a sentence, Zhang et al. (2003) manipulated two types of SCA word, high-noun-biased words (e.g. *包裝*) and low-noun-biased words (e.g. *交代*). The SCA words were preceded by a neutral sentence fragment and followed by a verb-biased context (e.g. *最後村長終於給了馮莉一個交代事件發生經過的機會*). They observed longer reading times for both types of SCA word compared to the unambiguous controls in the disambiguating regions and established that the high-noun-biased words caused greater processing difficulty than the

low-noun-biased words. The findings suggested that syntactic parsing principles could immediately assign the syntactic category to SCA words. Moreover, probabilistic constraints provided by the frequency of a word used as a noun or a verb can modulate the resolution of syntactic category ambiguity, supporting the constraint-satisfaction models. In the Zhang et al. (2003) study, neither the syntax-first models nor the constraint-satisfaction models were fully supported. In fact, the processing difficulty in the disambiguating regions can be explained without the predetermination of syntactic category. For most low-noun-biased SCA words in their manipulation, the different meanings were balanced rather than biased toward verbs. The longer reading times of these SCA words in the disambiguating regions could be due to the delay of resolving two different meanings, not to the conflict between verb-biased context and the noun assigned by syntactic parsing principles. One possible way to clarify this issue is to use the unbalanced VN and NV words in a context biased toward the subordinate meaning and syntactic category. The subordinate-biased context offers the best chance for syntactic parsing principles to show the influence on meaning activation and selection. In addition, the use of unbalanced VN words with a noun-biased context can show whether activation of the dominant verb meaning would be delayed in the noun-biased context that usually processes words immediately.

To sum up, the resolutions of Chinese lexical-semantic and syntactic category ambiguity are still unclear. Although some researchers have investigated how meaning dominance and contextual bias interact during Chinese lexical ambiguity resolution, the findings diverge and bolster different accounts. Moreover, there is a lack of thorough examination of how different combinations of meaning dominance and syntactic category are resolved during sentence comprehension.

The present study aims (1) to examine whether the syntactic category constraint can determine the semantic resolution of Chinese SCA words; and (2) to investigate whether the syntactic category of alternative meanings of Chinese homographs can influence the SBE during lexical ambiguity resolution. The purpose was to validate whether syntax-first models or constraint-satisfaction models can explain the semantic resolution of syntactic category ambiguity. We conducted an eye-movement experiment using the normal reading task. Four types of disyllabic biased homograph (NN, VV, VN, and NV) were embedded in sentences in which the sentential context was syntactically and semantically biased toward the subordinate meaning. Frequency-matched unambiguous words were used as control words and fit into the same sentence frames as their corresponding homographs. Previous studies demonstrated that gaze duration (GD), second-pass time, and spillover were important eye-movement measures for the SBE (Folk & Morris 2003; Lu 2012). According to syntax-first models, the SBE (A > UA) was expected for NN and VV homographs in the target region because the syntactic category constraint cannot distinguish between the alternative meanings, and both meanings were activated and competed. The SBE may last until the post-target region. In addition, the inherent properties of verb may cause delayed resolution of VV homographs as compared to NN homographs. In contrast, for VN and NV homographs, only the syntactic category-appropriate meaning was activated because the syntactic processor was able to select the meaning. Thus, no SBE was predicted in the target and post-target regions. However, according to constraint-satisfaction models, the SBE was predicted for four types of ambiguous word because multiple meanings were activated. The SBE may last until the post-target region because the subordinate-biased context conflicted with the activated dominant meaning. In addition, lexical-semantic information (e.g. processing difficulty of verb meaning, meaning dominance, etc.) may immediately affect meaning resolution.

2. Method

2.1 Participants

Forty undergraduate and graduate students (9 males and 31 females) aged between 19 and 26 years old (mean age = 21) were paid to participate in the experiment. All participants were native speakers of Mandarin Chinese and had normal or corrected-to-normal vision. None had participated in any previous norming study.

2.2 Materials and design

Eighty biased homographs, including four types (NN, VV, VN, and NV), and 80 corresponding unambiguous words (N_{NN}, V_{VV}, N_{VN}, and V_{NV}) were used as target words in the experiment. Word-form frequency, word stroke, and frequency of the first character obtained from *Academia Sinica Balanced Corpus of Modern Chinese* (Academia Sinica Balanced Corpus 2004) were matched for homographs and unambiguous words (Table 1). The two-way analysis of variance (ANOVA) with word type and ambiguity as independent variables was conducted for the word properties. For word-form frequency, there was a significant difference among word types ($F(3, 152) = 4.72$, $p < .01$). Post hoc comparisons using the Bonferroni test revealed that the frequency of VN was significantly higher than that of NN ($p < .01$) and that of VV ($p < .05$). There was no significant difference between homographs and unambiguous words, and the interaction was non-significant (Fs < 1, ps > .3). For word stroke and frequency of the first character, the main effects and the interaction were non-significant (Fs < 3, ps > .07).

Table 1: Examples of word materials, means, and standard deviations of word properties for each condition

Word type	Ambiguity	Word	Dominant / Subordinate meanings		Word property		
			Dominant	Subordinate	Frequency	Stroke	C1F
NN	A	風聲	消息；傳聞 (rumors; news)	風的聲音 (the sound of wind)	7.62 (6.6)	18.70 (5.29)	1149.59 (1134.19)
	UA	巨響	巨大聲響 (a loud crash)		6.8 (6.84)	19.4 (4.88)	881.99 (851.13)
VV	A	算帳	與人爭執或報復 (to avenge)	計算帳目 (to do accounts)	9.44 (8.89)	20.65 (4.97)	748.91 (773.62)
	UA	記帳	計算帳目 (to do accounts)		8.81 (7.74)	21.6 (4.04)	754.77 (778.4)
VN	A	效力	爲人出力或服務 (to serve)	功能、效果 (the efficacy)	14.88 (12.3)	18.60 (4.83)	942.63 (829.96)
	UA	功效	功能、效果 (the efficacy)		14.55 (12.77)	18.7 (5.22)	906.80 (927.07)
NV	A	制服	規定式樣的服裝 (the uniform)	用力量使人屈服 (to subdue)	11.88 (8.15)	20.95 (4.45)	1097.27 (1018.17)
	UA	逮捕	緝拿犯人 (to arrest)		8.34 (8.8)	20.1 (4.45)	734.24 (698.21)

Note: A = ambiguous words; UA = unambiguous words; C1F = frequency of the first character.

Sentences were designed in such a way that both the preceding and the succeeding sentential contexts were semantically and syntactically biased toward the subordinate meaning of the homographs. Pre-target, target, and post-target regions were all disyllabic Chinese words. A total of 80 sentence frames were constructed where the homograph and the corresponding unambiguous word could fit the context into the same position. The beginning of target words was located in the range of 14th–18th character in a sentence containing 25–27 characters (Table 2). Two experimental lists of trial sequences were established in such a way that the homograph-embedded and the corresponding unambiguous word-embedded sentences were not in the same list. Each list consisted of 90 sentences, comprising 40 homograph-embedded sentences (10 for each type), 40 unambiguous word-embedded sentences (10 for each group), and 10 filler sentences. The order of experimental sentences was randomized in each list, and each sentence was presented only once for each participant. The experiment consisted of 5 blocks of 18 trials, beginning with 2 filler trials. Around one-third of trials were followed by a true–false comprehension question.

Table 2: Examples of targets and sentences for each condition

Type	Conditions	Sentence		
		Preceding context	Target	Succeeding context
NN	A	由於強烈颱風肆虐，屋外的猛烈 Due to the terrible typhoon, outside the	風聲 sound of wind	持續一整晚沒有停止。 lasting overnight.
	UA	house there was strong	巨響 crashes	
VV	A	銀行的上級主管要求會計每天 The manager of bank asks the accountant	算帳 to do accounts	之後要立即向他報告帳目。 and then report to him.
	UA		記帳 to do accounts	
VN	A	看病的時候，醫生說過期的藥已經失去 When diagnosing, the doctor said the	效力 the efficacy	足以對抗病菌。 to fight the germs.
	UA	expired medicine had lost	功效 the efficacy	
NV	A	這名受過專業訓練的員警已經成功 The trained police officer has successfully	制服 subdued	搶劫銀行的通緝犯。 the fugitive who robbed the
	UA		逮捕 arrested	bank.

Note: A = ambiguous words; UA = unambiguous words.

Prior to the eye-tracking experiment, six norming studies were conducted to ensure the appropriate manipulations of word semantics and sentential contexts (Table 3). For word semantics, the ambiguous word should be a biased homograph, which has two distinct meanings with biased dominance (relative frequency of use). For sentential contexts, both syntactic and semantic context should be biased toward the subordinate meaning of homographs. A total of 160 Chinese sentences were chosen for the experiment, comprising 80 homograph-embedded (20 for each type) and 80 corresponding unambiguous word-embedded sentences.

Table 3: Means and standard deviations of words and sentences in all norming studies

Norming studies	Ambiguity	Type			
		NN	VV	VN	NV
Meaning dominance	A	0.86 (0.09)	0.88 (0.11)	0.84 (0.14)	0.9 (0.1)
	UA	0.99 (0.06)	1 (0)	1 (0)	1 (0)
Meaning relatedness	A	2.14 (0.79)	2.15 (0.86)	2.4 (1.22)	2.31 (0.94)
(1 = *not related*; 7 = *very related*)	UA	—	—	—	—
Word predictability	A	0.04 (0.05)	0.04 (0.07)	0.03 (0.07)	0.04 (0.1)
	UA	0.03 (0.05)	0.04 (0.05)	0.05 (0.06)	0.04 (0.06)
Syntactic category bias	A	0.96 (0.08)	0.96 (0.06)	0.96 (0.06)	0.97 (0.06)
	UA	Identical to the corresponding homographs			
Semantic bias	A	0.92 (0.07)	0.94 (0.06)	0.9 (0.12)	0.95 (0.07)
	UA	—	—	—	—
Syntactic category of target word	A	0.99 (0.05)	1 (0.02)	0.93 (0.13)	0.87 (0.19)
	UA	0.99 (0.02)	0.99 (0.02)	0.99 (0.04)	0.92 (0.22)
Plausibility	A	5.7 (0.72)	5.53 (0.68)	5.82 (0.46)	5.65 (0.67)
(1 = *not plausible*; 7 = *very plausible*)	UA	5.95 (0.54)	5.76 (0.54)	5.81 (0.49)	5.8 (0.47)

Note: A = ambiguous words; UA = unambiguous words.

2.2.1 Norming study 1: Meaning dominance

This norming study aimed to pick appropriate Chinese biased ambiguous words of four types (NN, VV, VN, and NV) and unambiguous control words for the present experiments. The dominant and the subordinate meanings of biased ambiguous words were determined by 40 participants' responses. Due to insufficient qualified biased ambiguous words after the rating, another group of 40 participants was invited to rate the meaning dominance for the additional ambiguous and unambiguous words. All the participants' native language was Mandarin Chinese.

One hundred and eight Chinese disyllabic ambiguous words and 140 Chinese disyllabic unambiguous words were collected from various resources, including *Dictionary of Homonyms in Modern Chinese* (Yuan 2001), *Word association for 600 Chinese homographs* (Hue et al. 1996), *Revisiting the Subordinate Bias Effect of Lexical Ambiguity Resolution: Evidence from Eye Movements in Reading Chinese* (Lu 2012), and *Academia Sinica Balanced Corpus of Modern Chinese* (Academia Sinica Balanced Corpus 2004). Unambiguous words were collected, which were suitable for embedding in the same position as the corresponding ambiguous words in sentences. Twenty ambiguous words had been rated in Lu (2012); thus, 88 ambiguous words and 140 unambiguous words were rated in this norming study. Two lists were constructed, and 20 participants were assigned to rate one of the lists. The ambiguous words and their corresponding unambiguous words were assigned to different lists. All words in each list were presented in a randomized order.

Participants used the words in the list one at a time to generate a comprehensible sentence according to the first meaning that came into their mind. In addition, they were instructed that the position of the target words in generated sentences was not restricted and that the meaning of target words in generated sentential context should be clear enough. Five practices were given to participants before the main task, and the rating could be completed in around one hour.

To obtain participants' first interpretation of each word, we examined the generated sentences to check the meaning of target words in each sentence based on the following online resources: *Revised Mandarin Chinese Dictionary* (1994) and *Chinese Wordnet* (*CWN*). Each word's meaning dominance was calculated as the proportion of participants' first interpretation. If all participants recognized a word with the same interpretation, then the meaning dominance of the word would be 1. Ambiguous words were regarded as biased if the meaning dominance was above 0.7. Their dominant meaning was the interpretation with which at least 70% of the participants recognized the words, and their subordinate meaning was the one with which less than 30% of the participants recognized them. Unambiguous words were chosen only when the meaning dominance was 1. Overall, 62 biased ambiguous words and 114 unambiguous words passed the meaning dominance rating.

2.2.2 Norming study 2: Meaning relatedness

The aim of rating meaning relatedness was to ensure that the dominant and the subordinate meanings of ambiguous words were semantically unrelated. Twenty undergraduate and graduate students were paid to participate in the rating. All the participants' native language was Mandarin Chinese, and none had participated in the meaning dominance rating.

Sixty biased ambiguous words (8 NN, 11 VV, 20 VN, and 21 NV) obtained from Norming study 1 were used to construct two understandable sentences for their dominant and subordinate meanings, respectively. A questionnaire was constructed, in which the ambiguous words, meaning definitions, and sentences were presented. Four lists were generated with different randomized word orders, and each was rated by five participants.

Participants read one ambiguous word at a time and then read two definitions of both the dominant and the subordinate meanings of the ambiguous word. They continued to read two example sentences. Subsequently, they were asked to rate the semantic relatedness between the two meanings on a 7-point scale (where 1 = *not related*; 7 = *very related*). Three practices were given to participants before the main task, and the rating could be completed in around half an hour.

The results showed that most ambiguous words were qualified homographs, that is, their meaning relatedness was below 3.5. Including 20 qualified biased homographs that had been rated in Lu's study, 80 homographs (20 for each type) were chosen for the eye-tracking experiment. The one-way ANOVA on meaning relatedness showed no significant difference across four types of homograph ($F(3, 76) = .34$, $p = .80$).

2.2.3 Norming study 3: Word predictability and syntactic category bias

A cloze task was used to ensure that both biased homographs and unambiguous words were unpredictable from the preceding context. In addition to word predictability, syntactic category bias rating was conducted to evaluate the syntactic category constraint from the preceding context. The sentences were rated by 40 participants. Due to insufficient qualified sentences after the rating, another group of 40 participants was invited to rate the additional sentences. Eighty undergraduate and graduate students were paid to participate in Norming studies 3–6. All the participants' native language was Mandarin Chinese, and none of them had participated in Norming studies 1 and 2.

There were 80 selected word pairs of homograph and unambiguous word, as well as 80 sentence frames into which both the homograph and the corresponding unambiguous word could fit. Both the preceding and the succeeding sentential contexts were semantically and syntactically biased toward the subordinate meaning of the homographs. A questionnaire was created, in which the preceding context, the target word (either ambiguous or unambiguous), the definitions of the dominant and the subordinate meanings of the homograph, the succeeding context, and the entire sentence were presented in order. Two lists were generated, each containing 40 sentences for homographs and 40 for unambiguous words. The sentence frame shared by the homograph and its corresponding unambiguous word was not presented in the same list. Each list was rated by 20 participants.

Participants were presented with the preceding context first, and had to write down a word to continue the sentence and to report the syntactic category of the word they had written. After the participants wrote down the word and the syntactic category, the target word (either ambiguous or unambiguous) was shown in the next column automatically. For the ambiguous targets, the definitions of both the dominant and the subordinate meanings were also shown simultaneously. Participants had to choose one definition that they considered more consistent with the preceding context, and then judge the syntactic category of the target word. After they judged the syntactic category of the target word, the succeeding context was presented and the participants had to choose one definition, again based on the succeeding context. For the unambiguous targets, participants only needed to judge the syntactic category of the target word. Finally, the entire sentence was shown and the participants evaluated the plausibility of the sentence on a scale of 1–7 (where 1 = *not plausible*; 7 = *very plausible*). Four practices were given to participants before the main task, and the entire questionnaire took around one hour to complete.

Word predictability was determined by the proportion of subjects who continued the sentences with the exact target words. The sentence materials were qualified when the predictability of target words was below 0.2, that is, less than 20% of the subjects predicted the exact target words in the cloze task. A two-way ANOVA with word type and ambiguity as independent variables was conducted for word predictability. The main effects and the interaction were non-significant (Fs < 1, ps > .90), indicating there were no significant differences among word types or between homographs and unambiguous words.

Syntactic category bias for each word was determined by the proportion of a certain syntactic category among 40 subjects' reports. It was expected that at least 90% of the subjects' reports would be consistent with the syntactic category of the subordinate meaning of the homographs (either noun or verb). The average biases for the four groups of corresponding unambiguous words were identical to those of the homographs, since they shared the same preceding context. A two-way ANOVA with word type and ambiguity as independent variables was conducted for syntactic category bias. The main effects and the interaction were non-significant (Fs < 1, ps > .77), indicating there were no significant differences among word types or between homographs and unambiguous words.

2.2.4 Norming study 4: Semantic bias

The aim of semantic bias rating was to ensure that the sentential contexts before and after homographs were both semantically biased toward the subordinate meaning. The participants and

materials were the same as those in Norming study 3; the procedure was described for Norming study 3. Semantic bias was established by the proportion of subjects who selected the subordinate meaning of the homographs based on both the preceding and the succeeding contexts. The results of one-way ANOVA on semantic bias of the sentential context showed no significant difference across four types of homograph ($F(3, 76) = 1.58$, $p = .20$), indicating that the semantic biases of the sentential context were equally strong for different types of homograph.

2.2.5 Norming study 5: Syntactic category judgment of target words

In the task of syntactic category judgment, participants have to judge the syntactic category of a certain word in sentences. This task has been adopted in previous research (Yang et al. 2009). The aim of syntactic category judgment was to ensure consistency between the syntactic category of target word and the syntactic category constraint from the preceding context.

Syntactic category of the target words was checked by the proportion of a certain syntactic category (either noun or verb) among 20 participants' reports. The value of syntactic category judgment of a word was 1 if all participants recognized that the word was a noun (for NN, VN, and unambiguous noun) or a verb (for VV, NV, and unambiguous verb). A two-way ANOVA with word type and ambiguity as independent variables was conducted for syntactic category judgment. There was a significant difference among word types ($F(3, 152) = 6.66$, $p < .001$). Post hoc comparisons using the Bonferroni test revealed that NV obtained significantly lower correctness on syntactic category judgment than NN ($p = .01$) and VV ($p < .01$). There was no significant difference between homographs and unambiguous words, and the interaction was non-significant (Fs < 3, ps > .1).

2.2.6 Norming study 6: Sentence plausibility

A sentence plausibility rating was conducted to ensure that all experimental sentences would make sense to native speakers of Mandarin. A two-way ANOVA with word type and ambiguity as independent variables was conducted for syntactic category bias. The main effects and the interaction were non-significant (Fs = 3, ps = .09), indicating there were no significant differences among word types and between homographs and unambiguous words.

2.3 Apparatus

An EyeLink 1000 Desktop Mount eye-tracking system (SR Research, Mississauga, Ontario, Canada) was used to record eye movements at the rate of 1,000 Hz. Eye movements were recorded from the dominant eye, though viewing was binocular. Sentence stimuli were presented in black on a gray background on a computer monitor (1,024 × 768 pixels). Each sentence was displayed on a single line in the middle of the screen. The size of each character was 32 × 32 pixels with a space of four pixels between characters. Participants were seated 70 cm away from the screen, and the width of a character with the space before it subtended approximately 1 degree of visual angle.

2.4 Procedure

The entire experiment was conducted in a dimly lit and noise-attenuated room. Prior to the experiment, the participants were tested for their dominant eye and sat in front of the monitor. They were assigned to one of the two experimental lists of trial sequences and were given the instruction presented on the monitor. After reading the instruction, the participants performed a nine-point calibration and validation procedure to ensure the accuracy of eye-movement recording. Given a successful calibration, the experimental trial would start. At the beginning of each trial, the participants were asked to fixate on a cross, located at the position where the first character of the sentence would be displayed. Once they fixated on the cross, the sentence was displayed and the cross vanished. The participants were instructed to read each sentence at their own pace. They were asked to fixate on a right-most cross, located below the last character of the sentence, and to press a button to terminate the current trial when they had understood the sentence meaning. Around one-third of sentences were followed by a true–false comprehension question. The participants answered the true–false question based on the information from the previous sentence by pressing either the left button 'yes' or the right button 'no'. Feedback was presented on the monitor after they pressed either button. Eight practice trials were presented at the beginning of the experiment. The entire experiment consisted of 90 trials, divided into 5 blocks, lasting about 40 minutes.

2.5 Data analysis

Two regions of interest (ROIs) were subject to analyses of eye movements: target word and post-target word (the two-character word following the target word). Fixation durations and probabilities on the ROIs were analyzed; these can be divided into two groups based on different definitions of fixations – the first-pass and the second-pass eye movement measures. The first-pass measures could primarily reflect processes of word recognition, while the second-pass measures represent integration of semantic and syntactic information (Rayner & Liversedge 2004). The definitions of the first-pass and the second-pass measures used in the present study are listed in (1) and (2), respectively.

(1) First-pass durations and probability measures:
   a. *First fixation duration* (*FFD*): the duration of the first fixation on a word independent of the number of fixations made on that word;
   b. *Single fixation duration* (*SFD*): the duration of the only fixation on a word;
   c. *Gaze duration* (*GD*): the sum of all fixation durations on a word before moving to the following word;
   d. *Skipping rate* (*SKIP*): the probability of skipping a word during first-pass reading;
   e. *Refixation rate* (*RFR*): the probability of refixating a word during first-pass reading.

(2) Second-pass durations and probability measures:
   a. *Go-past time* (*GPT*): the time from first entering a region until moving forward past that region;
   b. *Rereading time* (*RRT*): the sum of fixation durations returning to a given region after the first-pass reading;

c. *Total viewing time* (*TVT*): the sum of all fixation durations in a given region;
d. *Rereading rate* (*RRR*): the probability of returning to a given region after the first-pass reading;
e. *Regression-in rate* (*RIR*): the probability of making a regression onto a given region;
f. *Regression-out rate* (*ROR*): the probability of regressing out of a given region immediately following the first-pass reading on that region.

Data from five participants were excluded from the analyses and were replaced with new qualified data because of a much higher blinking rate. In addition, trials were eliminated from the analyses for the following reasons: (1) the first-pass fixation duration on the ROI was shorter than 80 milliseconds (msec) or longer than 800 msec, (2) the total viewing time on the ROI was shorter than 80 msec or longer than 1500 msec, (3) there was a blink on the ROIs, (4) fixations fell out of the range of ROIs, and (5) the fixation was at the beginning or the end of each trial. Overall, for the first-pass reading, the removed data accounted for 2.56% (target) and 2.31% (post-target). For the second-pass reading, the removed data accounted for 4.53% (target) and 4.31% (post-target). The average accuracy of the comprehension test was 91.56%. The present study used the linear mixed-effects (lme) model (Baayen et al. 2008) with crossed random effects for subjects and items to analyze the eye-movement data. The fixed effects of ambiguity (A–UA), syntactic category of target word (V–N), and syntactic category of the dominant meaning of homographs (V–N) were evaluated by using the lmer program of the lme4 package (Bates et al. 2012) in R 2.14.1 (R Development Core Team 2011). Simple effects were evaluated for if the target word was a noun or a verb, and if the dominant meaning of homographs was a noun or a verb. Finally, the ambiguity effect was also evaluated for each word type. Regression coefficients (*b*s), standard errors (*SE*s), *t* values (for durations), and *p* values (for probability measures) estimated from prior contrast tests are reported. We only reported effects for the absolute *t* value when they were greater than 1.8 in duration measures, and when the *p* value was smaller than .07 in probability measures.

3. Results

3.1 Target words

3.1.1 Duration measures

Means and standard errors of both the first-pass and second-pass duration measures for each condition on target words are shown in Table 4. None of these duration measures showed the syntactic category effect or the ambiguity effect.

3.1.2 Probability measures

Means and standard errors of both the first-pass and second-pass probability measures for each condition on target words are shown in Table 5. For the first-pass probability measures, *SKIP* showed no effect. *RFR* revealed that verbs were refixated more than nouns in terms of the target word's

Table 4: Means and standard errors of the duration measures for all conditions on target words

Duration measures (ms)		Type	Ambiguity		Effect size
			A	UA	A–UA
First-pass	FFD	NN	241.64 (4.72)	247.55 (5.19)	–5.91
		VV	244.48 (4.49)	254.06 (5.09)	–9.58
		VN	245.37 (5.27)	246.38 (5.28)	–1.01
		NV	253.32 (6.04)	245.54 (4.81)	7.79
	SFD	NN	241.15 (5.04)	248.08 (5.57)	–6.93
		VV	241.49 (4.86)	254.12 (5.69)	–12.63
		VN	244.81 (5.61)	246.32 (5.66)	–1.51
		NV	252.62 (6.47)	244.81 (5.13)	7.81
	GD	NN	261.78 (6.26)	276.09 (7.14)	–14.31
		VV	276.90 (7.18)	283.06 (7.27)	–6.16
		VN	267.05 (7.21)	265.52 (6.81)	1.53
		NV	284.04 (7.83)	265.32 (6.55)	18.72
Second-pass	GPT	NN	304.09 (11.48)	306.14 (10.13)	–2.05
		VV	321.36 (11.53)	322.55 (11.26)	–1.20
		VN	314.40 (11.37)	311.85 (12.68)	2.54
		NV	318.33 (11.16)	299.34 (10.82)	18.99
	RRT	NN	283.44 (20.53)	311.11 (21.09)	–27.66
		VV	394.56 (36.79)	323.87 (25.86)	70.70
		VN	292.04 (19.16)	314.13 (23.97)	–22.09
		NV	285.12 (16.49)	307.56 (23.77)	–22.44
	TVT	NN	317.85 (11.49)	307.95 (9.20)	9.90
		VV	344.29 (12.39)	320.60 (9.32)	23.69
		VN	321.70 (10.69)	318.00 (11.04)	3.70
		NV	322.47 (9.94)	310.00 (10.45)	12.48

Note: A = ambiguous words; UA = unambiguous words; FFD = first fixation duration; SFD = single fixation duration; GD = gaze duration; GPT = go-past time; RRT = rereading time; TVT = total viewing time.

syntactic category (b = .29, SE = .15, p = .05). The subordinate-by-dominant syntactic category interaction was significant (b = .30, SE = .15, p = .05); verbs were refixated more than nouns when the dominant syntactic category was a verb (b = .59, SE = .21, p < .01).

For the second-pass probability measures, *RRR* revealed that homographs were reread more than unambiguous words when their dominant meaning was a noun (i.e. NN and NV) (b = .42, SE = .21, p = 0.04). Both *RIR* and *ROR* showed no significant effects.

3.2 Post-target words

3.2.1 Duration measures

Means and standard errors of both the first-pass and second-pass duration measures for each condition on post-target words are shown in Table 6. For the first-pass duration measures, the effects

Table 5: Means and standard errors of the probability measures for all conditions on target words

Probability measures (%)		Type	Ambiguity		Effect size
			A	UA	A–UA
First-pass	SKIP	NN	30.43 (2.33)	28.83 (2.31)	1.60
		VV	24.43 (2.17)	30.43 (2.33)	–6.01
		VN	31.70 (2.37)	32.06 (2.36)	–0.36
		NV	28.87 (2.30)	31.36 (2.36)	–2.50
	RFR	NN	11.07 (1.91)	12.45 (2.00)	–1.38
		VV	14.53 (2.05)	13.28 (2.07)	1.24
		VN	9.06 (1.77)	8.27 (1.69)	0.79
		NV	13.87 (2.09)	9.36 (1.79)	4.51
Second-pass	RRR	NN	21.05 (2.09)	15.57 (1.86)	5.49
		VV	16.88 (1.91)	16.05 (1.89)	0.83
		VN	19.26 (2.03)	18.13 (1.96)	1.13
		NV	20.21 (2.06)	15.06 (1.83)	5.15
	RIR	NN	14.21 (1.79)	11.61 (1.65)	2.60
		VV	9.87 (1.52)	8.68 (1.45)	1.19
		VN	12.14 (1.68)	11.66 (1.64)	0.48
		NV	14.44 (1.80)	10.13 (1.54)	4.31
	ROR	NN	10.86 (1.91)	10.26 (1.84)	0.61
		VV	8.84 (1.66)	10.74 (1.89)	–1.90
		VN	12.88 (2.07)	10.90 (1.91)	1.98
		NV	8.46 (1.69)	7.92 (1.66)	0.53

Note: A = ambiguous words; UA = unambiguous words; SKIP = skipping rate; RFR = refixation rate; RRR = rereading rate; RIR = regression-in rate; ROR = regression-out rate.

of syntactic category and the effects of ambiguity were non-significant. For the second-pass duration measures, *GPT* revealed more go-past time for ambiguous words compared to unambiguous words (b = .05, SE = .02, t = 2.26), especially when the homographs' dominant meaning was a noun (b = .06, SE = .03, t = 2.19). *RRT* revealed greater rereading times for ambiguous words compared to unambiguous words when the homographs' dominant meaning was a verb (b = .14, SE = .06, t = 2.14), especially for VN (b = .24, SE = .08, t = 2.86). There was an ambiguity-by-dominant syntactic category interaction (b = .10, SE = .05, t = 2.06), indicating a larger ambiguity effect for dominant verb meaning, especially when the homographs' subordinate meaning was a noun (b = .16, SE = .06, t = 2.42). *TVT* revealed greater total reading times for ambiguous words compared to unambiguous words when the homographs' subordinate meaning was a noun (b = .05, SE = .03, t = 1.90).

3.2.2 Probability measures

Means and standard errors of both the first-pass and second-pass probability measures for each condition on post-target words are shown in Table 7. For the first-pass probability measures, *SKIP* revealed that the post-target following VN was more likely to be skipped than that following NV

Table 6: Means and standard errors of the duration measures for all conditions on post-target words

Duration measures (ms)		Type	Ambiguity		Effect size
			A	UA	A–UA
First-pass	*FFD*	NN	242.13 (5.02)	238.14 (4.94)	3.99
		VV	241.25 (5.64)	238.21 (5.16)	3.04
		VN	247.39 (5.27)	236.41 (5.19)	10.98
		NV	247.77 (6.42)	245.21 (6.10)	2.56
	SFD	NN	242.25 (5.12)	236.16 (5.03)	6.09
		VV	237.32 (5.66)	234.93 (5.14)	2.40
		VN	247.55 (5.48)	235.87 (5.60)	11.68
		NV	244.49 (6.89)	244.19 (6.47)	0.29
	GD	NN	260.78 (6.28)	261.70 (7.40)	–0.91
		VV	260.72 (7.84)	258.98 (7.34)	1.74
		VN	263.70 (7.03)	258.31 (7.34)	5.39
		NV	278.09 (8.65)	263.11 (7.15)	14.98
Second-pass	*GPT*	NN	319.00 (13.76)	294.81 (10.77)	24.18
		VV	319.45 (15.94)	294.06 (12.41)	25.39
		VN	296.93 (11.19)	288.56 (10.66)	8.38
		NV	333.34 (14.28)	302.82 (12.04)	30.52
	RRT	NN	265.31 (15.48)	308.38 (32.68)	–43.06
		VV	321.16 (27.38)	307.11 (30.36)	14.06
		VN	372.89 (28.72)	288.92 (23.36)	83.97
		NV	262.11 (19.45)	307.85 (33.14)	–45.74
	TVT	NN	296.54 (8.55)	294.23 (9.85)	2.31
		VV	309.16 (11.57)	304.03 (12.22)	5.14
		VN	324.37 (12.73)	303.18 (11.38)	21.19
		NV	322.06 (11.10)	310.79 (11.19)	11.27

Note: A = ambiguous words; UA = unambiguous words; FFD = first fixation duration; SFD = single fixation duration; GD = gaze duration; GPT = go-past time; RRT = rereading time; TVT = total viewing time.

(b = .31, SE = .16, p = .06). There was an ambiguity-by-subordinate syntactic category interaction (b = .15, SE = .08, p = .05). The ambiguity effect was larger in the post-target region following NV compared to following NN (b = .21, SE = .11, p = .07). The post-target following VV and NV homographs was more likely to be skipped than that following unambiguous words (b = .22, SE = .11, p = .05). The post-target following an NV homograph was more likely to be skipped than that following unambiguous words (b = .31, SE = .16, p = .05). In addition, *RFR* revealed that the post-target was more likely to be refixated when the homographs' dominant meaning was a noun compared to when it was a verb (b = –0.40, SE = .22, p = .07). *RFR* showed no significant effects of ambiguity.

For the second-pass probability measures, *RRR* and *RIR* revealed a higher probability of rereading and regression-in when the homographs' dominant syntactic category was a verb, especially when the homographs' subordinate syntactic category was a verb (ps < .01). *RRR* and *ROR* revealed a higher probability of rereading and regression-out for homographs compared to unambiguous

words, especially when the homographs' subordinate syntactic category was a verb and when the homographs' dominant syntactic category was a noun (*p*s < .05). In addition, *RRR* revealed the ambiguity-by-subordinate-by-dominant syntactic category interaction (b = .21, SE = .11, p = .05). The ambiguity-by-dominant syntactic category interaction was significant when the homographs' subordinate syntactic category was a noun (b = –0.31, SE = .15, p = .04), indicating a larger ambiguity effect for NN than for VN. The ambiguity-by-subordinate syntactic category interaction was significant when the homographs' dominant syntactic category was a verb (b = .30, SE = .15, p = .05), indicating a larger ambiguity effect for VV than for VN. *ROR* revealed a higher probability of regression-out for homographs compared to unambiguous words when the homographs' subordinate syntactic category was a noun (b = .46, SE = .22, p = .04). Finally, both *RRR* and *ROR* revealed the ambiguity effect for NN; *RRR* also revealed the ambiguity effect for VV; *ROR* revealed the ambiguity effect for NV (*p*s < .05).

Table 7: Means and standard errors of the probability measures for all conditions on post-target words

Probability measures (%)		Type	Ambiguity		Effect size
			A	UA	A–UA
First-pass	*SKIP*	NN	35.04 (2.42)	37.24 (2.44)	–2.21
		VV	45.04 (2.51)	41.79 (2.50)	3.24
		VN	43.70 (2.52)	45.15 (2.52)	–1.45
		NV	38.97 (2.47)	32.65 (2.38)	6.33
	RFR	NN	9.09 (1.81)	9.39 (1.87)	–0.30
		VV	8.49 (1.92)	10.81 (2.09)	–2.32
		VN	5.96 (1.61)	8.84 (1.94)	–2.87
		NV	14.10 (2.28)	11.15 (1.96)	2.95
Second-pass	*RRR*	NN	16.62 (1.91)	12.53 (1.69)	4.09
		VV	17.78 (1.94)	12.60 (1.70)	5.19
		VN	17.20 (1.94)	19.22 (2.01)	–2.03
		NV	15.04 (1.84)	13.62 (1.74)	1.41
	RIR	NN	8.71 (1.45)	7.57 (1.35)	1.14
		VV	10.57 (1.56)	7.09 (1.32)	3.48
		VN	11.11 (1.62)	12.47 (1.69)	–1.36
		NV	6.86 (1.30)	6.94 (1.29)	–0.08
	ROR	NN	17.06 (2.37)	10.25 (1.95)	6.82
		VV	13.21 (2.33)	9.09 (1.94)	4.12
		VN	11.01 (2.12)	8.84 (1.94)	2.17
		NV	15.45 (2.37)	8.56 (1.75)	6.89

Note: A = ambiguous words; UA = unambiguous words; SKIP = skipping rate; RFR = refixation rate; RRR = rereading rate; RIR = regression-in rate; ROR = regression-out rate.

4. Discussion

The results of the delayed SBE for lexical-semantic (NN and VV homographs) and syntactic category (VN and NV homographs) word ambiguity in a biased preceding context support the

constraint-satisfaction models. The data are inconsistent with the prediction of the syntax-first models that syntactic structural constraint alone can determine the resolution. In fact, both semantic and syntactic category information could contribute to lexical ambiguity resolution. The absence of the SBE on the target words may result from two types of constraint. One is the semantic constraint from the preceding context. The subordinate-biased semantic information facilitates the activation of the subordinate meaning. Readers may not experience processing difficulty immediately if the activation of the dominant but context-unintended meaning takes time. The other constraint is the inherent processing difficulty of syntactic category. Our findings indicate that verbs, compared with nouns, need more time to be processed either as a dominant or a subordinate meaning of homographs. Thus it may delay the SBE until the second-pass reading on the post-target words.

We demonstrated the syntactic category effect of both dominant and subordinate meanings for homographs on eye-movement measures of target and post-target words. For fixation measures on target words, the syntactic category effect of subordinate meaning was observed in the first-pass probability measure *RFR*, indicating that verbs are inherently more difficult to process than nouns. This finding is consistent with the study of Sereno (1999), in which subjects responded to nouns significantly faster than to verbs in both the categorization task and the lexical decision task. For the dominant meaning that was incongruent with the preceding context, no significant syntactic category effect was found on the target words. Instead, the effect was shown on post-target words. For the first-pass reading, the lower skipping rate and higher refixation rate for nouns relative to verbs indicated that the dominant meaning as noun is activated to a certain extent and is difficult to integrate with the context biased toward the subordinate meaning. On the other hand, the dominant meaning as verb needs time to be activated, and the difficulty of integration with the subordinate-biased context may occur late. As a consequence, the semantic resolution was not observed until the second-pass reading (*RRR* and *RIR*) on the post-target words.

The syntactic category effect of homographs, in consensus with the literature, suggested that processing verbs is more difficult than processing nouns. Critically, the findings demonstrated the effects in both the situation when the verb meaning is context-intended and the situation when the verb meaning is context-unintended. The processing difficulty of verbs could be due to different syntactic or semantic features between nouns and verbs, including the assignment of thematic roles and the reference to an object or an action (Vigliocco et al. 2011). Related to the goal of our study, the processing difficulty of verbs may result in delay of the ambiguity resolution effects. The verb delay can explain why Zhang et al. (2003) found no ambiguity effect on SCA words with the verb-biased context and the smaller effect of low-noun-biased SCA words than high-noun-biased SCA words in the disambiguating regions. It may be unnecessary for them to assume the SCA words were assigned to a syntactic category by accessing specific syntactic parsing principles. Both Zhang et al. (2003) and our results are in agreement with the constraint-satisfaction models when the nature of noun and verb processing is considered to be one of the constraints.

In the present study, the SBE of both noun and verb was observed in the second-pass reading of the post-target words. Thus the verb delay cannot account for all the findings, especially for the NN homographs. One of the possible reasons for the late effect may be the strength of semantic constraint before the ambiguous words. In our stimuli, the rating of semantic bias showed that more than 90% of the participants could interpret the homographs as the context-intended meaning when provided with the preceding context. Some studies have reported that a strongly biased context may

result in selective access or may eliminate the SBE during lexical ambiguity resolution (Seidenberg et al. 1982; Vu & Kellas 1999; Vu et al. 1998, 2000). For example, Seidenberg et al. (1982) found lexical ambiguity resolution was selective when the preceding context involved a lexical-priming word (i.e. a word semantically related to either meaning). Vu et al. (1998) manipulated the semantic specificity of verb and subject noun to investigate whether lexical ambiguity resolution can be influenced by the strength of sentence constraints. Their results showed multiple access in the ambiguous condition (e.g. *He located the bat.*) but selective access in the strongly biased condition (e.g. dominant-biased: *He splintered the bat.*; subordinate-biased: *He wounded the bat.*) whenever the dominant or subordinate meaning was context-intended. The evidence supported the idea that the extent of semantic constraints could restrict lexical ambiguity resolution to the context-appropriate meaning. However, both studies used the naming task, which was unable to detect the effects that might occur late in processing the succeeding sentence. The late SBE of eye-fixation times on the post-target words suggested that the semantic constraint would temporally suppress but not eliminate the context-inappropriate meaning.

Folk & Morris (2003) observed a delayed SBE for VN homographs and suggested that syntactic category assignment can restrict semantic resolution to the syntactically appropriate meaning of SCA words. Our findings showing that an SBE effect for NV homographs clearly refute their explanation. Furthermore, it is worth noting that NV homographs numerically showed a larger SBE than VN homographs on both target and post-target words. For NV, both the first-pass (*FFD*, *SFD*, *GD*, *RFR*) and second-pass (*GPT*, *RRR*, *RIR*) measures revealed the SBE on the target words, but this was not the case for VN. On the post-target words, the SBE also was larger for NV compared to VN in *GD*, *GPT*, and *ROR*. The verb delay hypothesis can account for the different patterns between NV and VN homographs by assuming that semantic constraint elicits the subordinate meaning immediately. The less pronounced SBE for VN homographs could be due to the delayed processing of dominant meaning as verb. This explanation implies that the SBE for NV on the target words may reflect the cost of the competition between two different meanings. However, an alternative explanation is that semantic constraint does not activate the subordinate meaning immediately, especially in the case of verb-biased context initiating the subordinate verb meaning. The SBE for NV on the target words could reflect the cost of the conflict between the verb-biased context and the dominant noun meaning that is activated immediately. Whether the SBE for NV on the target words is due to the meaning competition or the resolution of the conflict between the context and the dominant meaning cannot be distinguished in the present study. Further experiments that eliminate the semantic constraint before reading the SCA words may clarify the two possible explanations.

In conclusion, our data support the constraint-satisfaction models. The constraints utilized during lexical ambiguity resolution may include meaning frequency, inherent processing difficulty of syntactic category, and the strength of semantic and syntactic context. The SBE could reflect the resolution of two simultaneously activated meanings, or the resolution of conflict between the context and the incongruent meaning. More studies are needed to understand the nature of the different resolutions and the role of different constraints in processing homographs in a sentence.

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Jie-Li Tsai (corresponding author)
Department of Psychology
National Chengchi University
64, Sec. 2, ZhiNan Road
Taipei 116, Taiwan
jltsai@nccu.edu.tw

詞性與語義限制對詞彙歧義解困的影響：中文歧義詞處理的眼動研究

陳柏亨　　蔡介立
國立政治大學

本研究的目的有二：（一）檢驗詞性限制能否決定中文詞類歧義詞的語義解困；（二）檢驗中文歧義詞語義的詞性是否會影響次要語義偏向效應 (subordinate-biased effect)。實驗中將四種不同類型 (NN, VV, VN, NV) 的中文非均勢同形異義詞 (biased homograph) 置於語法及語義皆偏向次要語義的句子裡，每個歧義詞皆搭配一個詞頻相當的單義詞，置於相同的句型作爲控制，並使用眼動儀記錄受試者閱讀句子的眼動表現。實驗結果發現：（一）四種類型的歧義詞之次要語義偏向效應只反映在目標詞後區域的二次閱讀指標上；（二）就效果量而言，NV 歧義詞的次要語義偏向效應在目標詞與目標詞後兩個區域，皆比 VN 歧義詞來得大。整體而言，本研究結果顯示，詞性限制並不是影響中文詞類歧義詞語義解困的唯一因素，此結果支持制約滿足模型 (constraint-satisfaction models)，並不符合句法優先模型 (syntax-first models) 的預測。

關鍵詞：詞類歧義，詞彙歧義解困，次要語義偏向效應