

**The interaction of syntactic and lexical information
sources in language processing:
The case of the noun-verb ambiguity^{1*}**

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This paper reports the results of a lexical decision experiment and a self-paced reading experiment that investigate the interaction between syntactic and lexical information in on-line language processing, using the noun-verb ambiguity in English. The results of both experiments provide support for the hypothesis whereby syntactic and lexical information are two independent factors in the process of sentence comprehension, consistent with previous work in the sense-ambiguity processing literature. Our results therefore add to the body of literature that demonstrates that the process of language comprehension is guided by numerous independent information sources, rather than syntactic information alone, as some of the earlier proposals in the field of sentence processing hypothesized.

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*A fly was very close to being called a "land,"
cause that's what they do half the time.*

Mitch Hedberg

1. Introduction

Research in the language comprehension literature has demonstrated that people use a variety of information sources in the moment-by-moment comprehension of sentences, including lexical information, syntactic structure, the plausibility of the described events, the discourse context, and – for auditory input – prosody (Tanenhaus & Trueswell, 1995; Gibson & Pearlmutter, 1998). An important architectural question in this literature is whether all or only some of these information sources can *guide* the process of sentence comprehension, where guiding processing means operating independent of other information sources to determine the range of possible interpretations, as opposed to deciding between or among the interpretations suggested by other information sources. An early hypothesis in the literature was that only syntactic information can guide the process of sentence comprehension (Fodor, Bever & Garrett, 1974; Frazier, 1978; Frazier & Fodor, 1978; Fodor, 1983), with information sources such as plausibility and context being used to decide among the syntactic alternatives (e.g., Crain & Steedman, 1985). However, subsequent research has established that information sources other than syntax are available to comprehenders as early as can be measured (e.g., MacDonald, Pearlmutter & Seidenberg, 1994;

Trueswell, Tanenhaus & Garnsey, 1994; Tanenhaus et al., 1995) and may in fact guide the process of sentence comprehension (see also Tyler & Marslen-Wilson, 1977 and Marslen-Wilson & Tyler, 1987). In particular, semantic information and the plausibility of the described events (Kuperberg et al., 2003; Kim & Osterhout, 2005) and the local discourse context (Altmann & Kamide, 1999; Grodner, Gibson & Watson, 2005) have been shown to guide sentence processing, independent of syntactic information. The focus of the current paper is to investigate whether lexical information guides sentence comprehension, independent of syntactic information. Another way to frame this question is in terms of whether syntactic context constrains lexical access: if so, then lexical access is not independent of syntactic processing; if not, then lexical access proceeds independently of the preceding syntactic context.

Research from the lexical access literature has established that lexical processing proceeds independent of the existing *semantic* context. Two paradigms have provided the evidence in support of this claim: (a) a semantic priming paradigm, where participants process a sentence and perform a lexical decision task on a word that may be related to one of the words in the sentence; and (b) a reading paradigm, where reaction time is measured for each word in the sentence. Using the semantic priming paradigm, it has been shown that for equi-biased sense-ambiguous words (e.g., for a word like *bug*, which is ambiguous between *insect* and *recording device* senses), both interpretations are initially accessed, independent of the semantic context (Swinney, 1979; Tanenhaus, Leiman & Seidenberg, 1979; Seidenberg et al., 1982). Furthermore, when the context is biased towards the lower-frequency interpretation of an ambiguous word, both the low and high frequency interpretations are accessed, but when the context is biased toward the higher-frequency interpretation, only the high frequency interpretation is accessed (Tabossi, Colombo, & Job, 1987; Tabossi, 1988).

These results suggest that semantic context and lexical frequency are two independent sources of information that the processor can use in comprehending words: when one or both constraints support the access of a lexical entry, then access of that lexical entry occurs. When no constraints support a particular lexical entry (as e.g., in the case of a low-frequency reading occurring in an unsupportive context), there is no evidence of it being accessed.

In the reading paradigm, when the context is neutral with regard to the different meanings of an equi-biased sense-ambiguous word, it takes comprehenders longer to process the word, compared to a biased ambiguous word or an unambiguous control word (Duffy, Morris & Rayner, 1988; Rayner, Pacht & Duffy, 1994; Binder & Rayner, 1998; Binder, 2003). This has been explained in terms of competition between the two equally available meanings of the balanced word (e.g., Duffy et al., 1988). Furthermore, when the context is consistent with the subordinate meaning of a biased sense-ambiguous word, it takes comprehenders longer to process the biased ambiguous word, compared to unambiguous controls. This phenomenon has been termed the subordinate bias effect (Rayner et al., 1994), and has been argued to reflect competition between the two meanings of the word, where the dominant meaning is highly available due to its frequency, and the subordinate meaning is made available by the contextual information. These results dovetail nicely with the evidence from the semantic priming paradigm: both sets of results suggest that lexical frequency and semantic context are two independent sources of information that the processor uses in comprehending words in a sentence.

There has been less research investigating lexical access in different *syntactic* contexts. Most of the evidence relevant to this question has come from the semantic priming paradigm. In particular, it has been shown that for equi-biased words that are ambiguous with respect to their syntactic

category (i.e., words that are ambiguous between a noun and a verb like *rose* or *watch*), both interpretations are initially accessed, independent of the syntactic context (Tanenhaus et al., 1979; Seidenberg et al., 1982). Much like the results discussed above had suggested that lexical processing occurs independent of semantic context, this result suggests that lexical processing occurs independent of syntactic context.

There is little evidence from the literature manipulating lexical frequencies of the different meanings of category-ambiguous words and syntactic context using a reading method. In an early paper investigating these constraints in reading, Frazier & Rayner (1987) examined noun-verb ambiguous words like *trains* in sentence contexts that were initially consistent with either reading (e.g., *The desert trains ...*) and then were disambiguated towards one syntactic category or the other. It was observed that the ambiguous word was processed *faster* than its unambiguous control, contrary to the predictions of the independent constraints hypothesis, which would predict slower processing (due to competition), all other factors being equal. However, MacDonald (1993) demonstrated that the relatively fast times for reading the ambiguous words in Frazier & Rayner's experiment were more likely due to the fact that Frazier & Rayner's unambiguous control conditions were pragmatically odd in a null context, because of the presence of a demonstrative determiner (e.g., *these desert trains...*; *this desert trains...*). MacDonald then showed that when more suitable unambiguous control sentences were used, the temporarily ambiguous words were not processed any faster. MacDonald further argued that a lexically-based processing theory could account for the observed pattern of results. However, MacDonald's experiments did not evaluate whether lexical information was independent of syntactic context.

Recently, more direct tests of whether syntactic and lexical constraints are independent have been conducted using a reading method. In

one set of eye-tracking studies, Boland & Blodgett (2001) manipulated the syntactic context to be biased to expect either a noun (e.g., *She saw his ...*), or a verb (e.g., *She saw him ...*), for sixteen words that were ambiguous between noun and verb readings (e.g., *duck, play*), with the bias toward one of the categories varying continuously.² Boland & Blodgett observed a significant correlation between lexical bias and initial fixation times in the conditions where the syntactic context created an expectation for a noun (more verb-biased items took longer to process), and a marginal correlation in the conditions where the syntactic context created an expectation for a verb (more noun-biased items took longer to process). This evidence suggests that lexical information affects processing difficulty even in cases where syntactic information provides a strong cue to the correct interpretation. However, there were three issues in Boland & Blodgett's experiments that weaken this interpretation: (a) a relatively small number of noun-verb ambiguous items (sixteen) was included; (b) the result was only reliable in the noun contexts; and (c) two of sixteen items had to be removed in order for the correlations to be significant (Boland & Blodgett justified the removal of these two items by arguing that the two measures of establishing lexical bias – corpus counts and sentence completion norms – were inconsistent for these items). The generalizability of these results is therefore questionable.

In another set of eye-tracking reading studies, Folk & Morris (2003) failed to find a subordinate bias effect for verb-biased noun-verb ambiguous words in noun contexts in early eye-tracking measures (although they did find such an effect in second pass times). As in the case of Boland &

² Boland & Blodgett also varied the discourse context prior to the critical sentence, so that it was biased toward the noun or the verb reading. We focus on the conditions where the discourse context was consistent with the syntactic context, because the data patterns with regard to the relationship between lexical bias and syntactic context are easiest to interpret in these conditions.

Blodgett's studies, however, there were issues with Folk & Morris's experiments that make interpretation of their results difficult. In particular, in their first experiment, Folk & Morris used rich syntactic and semantic contexts (e.g., *Biking through Utah, the cyclist lost a spoke* (vs. unambiguous control *jacket*) *in the mountains*). Given that not only syntactic information but also semantic information in the preceding context points toward the subordinate reading of the ambiguous word, it is perhaps unsurprising that lexical information alone is not strong enough to override these two information sources. In their second experiment, Folk & Morris used more minimal syntactic contexts (similar to Experiment 2 in the current paper). However, in that experiment the lexical bias of the critical noun-verb ambiguous words may not have been sufficiently strong (the mean bias was .63, with a range of 50-.68; cf. a bias of .83 for verb-biased words and .94 for noun-biased words in Experiment 2 in the current paper). In summary, the lack of a subordinate bias effect in Folk & Morris's studies may have been due to (a) their use of overly rich semantic contexts in their first experiment; and (b) weak lexical biases in their second experiment. Consequently, their studies are still consistent with the independence of lexical and syntactic constraints.

More recently, a subordinate bias effect has been observed with respect to a category-ambiguous word: the word *that*, which is ambiguous between a determiner and a complementizer, and is strongly biased in written text toward the complementizer reading (Tabor, Juliano & Tanenhaus, 1997; Gibson, 2006). Tabor et al. (1997) and Gibson (2006) examined the processing of this word in syntactic environments that are inconsistent with the complementizer interpretation, as in (1a) and (2a):

- (1) a. The lawyer visited that skilled surgeon before the hearings began.
b. The lawyer visited those skilled surgeons before the hearings began.
- (2) a. The lawyer for that skilled surgeon asked for a raise.
b. The lawyer for those skilled surgeons asked for a raise.

Both research groups found that the region consisting of *that* and the following two words (*that skilled surgeon* in (1a) and (2a)) was processed more slowly than the corresponding region in the control sentences (*those skilled surgeons* in (1b) and (2b)). One plausible explanation for these results is in terms of the subordinate bias effect: the complementizer reading of the word *that* is available due to its frequency, and the determiner reading is made available by the syntactic context, leading to competition between the two interpretations, and consequently slower reading times than in the control cases, where no such competition occurs.³ This evidence is therefore consistent with the hypothesis whereby lexical information and syntactic information are independent factors in on-line sentence comprehension. However, a limitation of these studies is that they are based on reading time data for the ambiguity of a single word, the word *that*.

Finally, a recent event-related potentials (ERP) study on category-ambiguous words provides further evidence for the independence of lexical and syntactic constraints. In particular, Thierry et al. (2008) investigated a

³ Tabor et al. discuss the processing slowdown in examples like (1a) in terms of context-dependent lexical access (similar to proposals by Swinney & Hakes, 1976; Cairns & Hsu, 1980; Carpenter & Daneman, 1981; Simpson, 1981), but other results from the literature on lexical access in context make this interpretation unlikely (Duffy et al., 1988; Rayner et al. 1994, among others). Furthermore, Gibson (2006) provides direct evidence against the context-dependent lexical access interpretation of this particular ambiguity.

phenomenon where a word is used in a syntactic context that is inconsistent with the word's dominant category meaning. Such conversion of one part of speech into another (what the authors call "functional shift") is a common literary device. Thierry et al. focused on materials from Shakespeare's writings where this device is used extensively. For example, one item from Thierry et al.'s study was *I know you don't want to speak, but lip something loving in my ear*, where the word *lip* – most frequently used as a noun – is used as a verb, to mean *whisper/speak softly*. In their functional shift condition, Thierry et al. observed two components that have been argued to reflect syntactic processes: a Left Anterior Negativity (LAN) and a P600 component, a positive-going waveform peaking around 600 ms after the onset of the critical word (see e.g., Kaan, 2007, for an overview). These results suggest that comprehenders access the syntactic-context-inappropriate lexical meaning (e.g., the noun reading of *lip* in the example above), which leads to difficulty in integrating the word with the preceding syntactic context.

To summarize the results from the literature reported above: (1) multiple meanings are activated during lexical access under most circumstances (except for accessing the low-frequency meaning of a word that appears in a context that supports its high-frequency meaning), (2) biased ambiguous words can cause processing difficulty when the context supports the low-frequency interpretation, resulting in a subordinate bias effect, (3) with respect to syntactic category ambiguities, the subordinate bias effect has been observed for the category-ambiguous word *that* (Tabor et al., 1997; Gibson, 2006), but (4) the evidence for a subordinate bias effect in other category ambiguities, such as the noun-verb ambiguity in English, is not as strong (e.g., Boland & Blodgett, 2001; cf. Folk & Morris, 2003). Thus, although previous literature strongly suggests that lexical and syntactic information are likely to guide interpretation independently, the existence of

a subordinate bias effect in a productive syntactic category ambiguity has not yet been demonstrated convincingly.

To address this gap in the literature, the current studies seek to examine the interaction of lexical frequency and syntactic context in sentence processing using a productive syntactic category ambiguity: the noun-verb ambiguity in English. These studies are thus similar to those of Boland & Blodgett and Folk & Morris, but with more items, more sophisticated analyses, and materials presented in minimal syntactic contexts without any preceding semantic / discourse context, in order to narrow in on the interaction of only lexical frequency and syntactic context. If lexical information guides interpretation independent of syntax, then we should observe a subordinate bias effect, much like that observed by Tabor et al. (1997) and Gibson (2006) with respect to the complementizer / determiner ambiguity of *that*, such that a word with a dominant noun interpretation is read slowly in a verb context, and a word with a dominant verb interpretation is read slowly in a noun context.

To select a set of materials for our experiments, we initially conducted a study using meta-linguistic judgments (Norming Study 1). Subsequently, we used the materials selected based on the results of Norming Study 1 in an elicited production study (Norming Study 2) and in a corpus study. As will be discussed below, the results from all three studies were highly correlated ($r_s > .75$), suggesting that the lexical biases in the materials used in Experiments 1 and 2 are reliable. We will now describe the methods and the results of the two norming studies and of the corpus study. We will then go on to describe the two experiments.

2. Norming Study 1

Methods

Four independent raters were presented with a list of 240 noun-verb ambiguous items (generated by two of the authors, Fedorenko and Gibson). Each rater was asked to provide a judgment for each word with regard to whether the word is more likely to be a noun, a verb, or equally likely to be both⁴.

The goal of the study was to select three subsets of words which would be noun-biased, verb-biased and equi-biased.

Results

For each word, the number of noun-biased, verb-biased and equi-biased responses was counted. The following criteria were applied to select the three subsets of words. A word was considered noun-biased if it had 3 or 4 noun-biased responses and 0 verb-biased responses. Similarly, a word was

⁴ In the current studies we focus on the syntactic category ambiguity of the noun-verb ambiguous words and do not take into consideration (a) the degree of semantic relatedness between the noun and the verb readings, or (b) the within-category sense ambiguities for the noun and/or the verb reading. Both of these factors may play a role in the relationship between syntax and lexical information. We decided to ignore differences among noun-verb ambiguous words along these dimensions for two reasons. First, we wanted to use a large set of items (an advantage over previous studies), and having additional constraints on the materials would have decreased the potential set of noun-verb ambiguous words. And second, many decisions about how related some meanings are to one another (either between the noun and the verb reading, or among the different noun or verb readings) are subjective, with the consequence that estimating frequencies for different senses separately is less straightforward than estimating the frequencies of the noun vs. the verb reading (the latter is straightforward because the contexts in which nouns and verbs are used are almost entirely non-overlapping).

considered verb-biased if it had 3 or 4 verb-biased responses and 0 noun-biased responses. A word was considered equi-biased if it had no more than 2 noun-biased responses and no more than 2 verb-biased responses. Based on these criteria, 60 words were selected for each bias group for a total of 180 items.

3. Norming Study 2

Methods

This study used an elicited production task to determine the bias of the ambiguous words. Fifty-six participants from MIT and the surrounding community took part in the study. All were between the ages of 18 and 40, native speakers of English and naive as to the purposes of the study. None had participated in Norming Study 1. All participants were paid for their participation.

The 180 items selected in Norming Study 1 were used in this study. The list was divided in half, such that each participant only saw 90 critical items (30 noun-biased, 30 verb-biased and 30 equi-biased). This was done due to the time-consuming nature of the task (written sentence generation), such that the participants would not have to spend more than one hour on the experiment. 90 category-unambiguous fillers were included in addition to the critical items (these included 30 verbs, 20 prepositions, 20 adjectives and 20 adverbs; no unambiguous nouns were included because we reasoned that there is an a priori bias to treat single words as nouns in this sentence generation task). Four pseudo-random lists were created (two for each of the two halves of the target items) such that no more than two ambiguous words appeared in a row, and then four additional lists were created by reversing

the order of these lists. Thus there were eight experimental lists. Seven participants saw each of the lists.

Participants were instructed to create a short (4-7 words long) sentence with each of the words. They were told to write the first thing that came to their mind. They were also told that they could change the form of the words: for example, they could make a noun plural and put a verb in the past or future tense. The study took approximately one hour to complete.

Results

For each word the number of noun and verb uses was counted by hand-parsing the participants' responses. 6.8% of the responses could not be coded as a noun or a verb use: either the word remained ambiguous or it was used in a different category (e.g., as an adjective). The analysis of the responses revealed a smooth distribution of the lexical bias across the items, as shown in Figure 1. A correlation analysis between the results of the two norming studies revealed a highly significant correlation ($r=.82$; $F(1,178)=356.3$; $p<.001$).

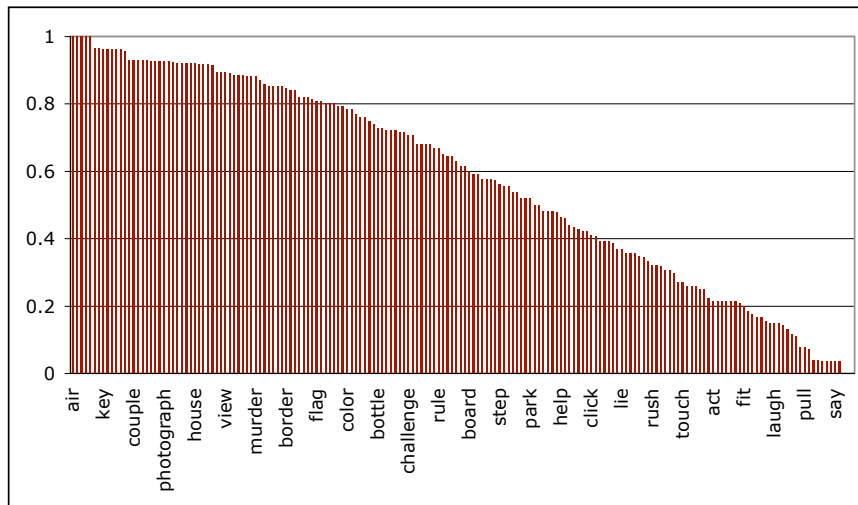


Figure 1. The distribution of the responses for 180 target items in Norming Study 2, sorted by the percentage of noun responses (plotted on the y-axis).

[Note that although the graph contains all 180 data points, the words displayed on the x-axis are a small subset of the 180 words, because it would be impossible to display them all legibly.]

4. Corpus Study

Methods

The CELEX database (Baayen et al., 1995) was used to determine the bias of the ambiguous words. As in Norming Study 2, the items selected in Norming Study 1 were used in this study. Five of the items were not found in the CELEX database, so only 175 items were included. Lemma frequencies (normalized out of 1,000,000) were used. The relative biases were calculated by adding the frequency values for the noun and for the verb readings and then dividing the noun and the verb frequency value by the summed value.

Results

Similar to Norming Study 2, the analysis of the relative biases revealed a smooth distribution across the items, as shown in Figure 2.

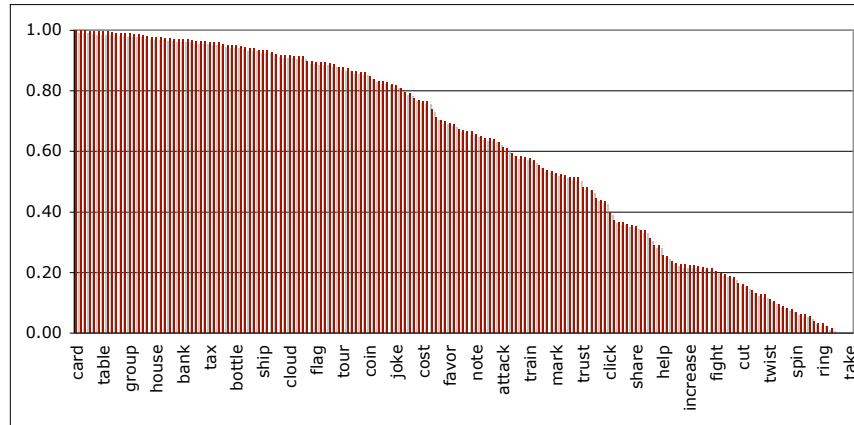


Figure 2. The distribution of the responses for 175 target items in the Corpus Study, sorted by the noun bias (plotted on the y-axis). [Note that although the graph contains all 175 data points, the words displayed on the x-axis are a small subset of the 175 words, because it would be impossible display them all legibly.]

A correlation analysis between the results of the Corpus Study and the two Norming Studies revealed highly significant correlations: Corpus Study and Norming Study 1 ($r=.75$; $F(1,173)=221.7$; $p<.001$); Corpus Study and Norming Study 2 ($r=.82$; $F(1,173)=367.5$; $p<.001$) (Figure 3).

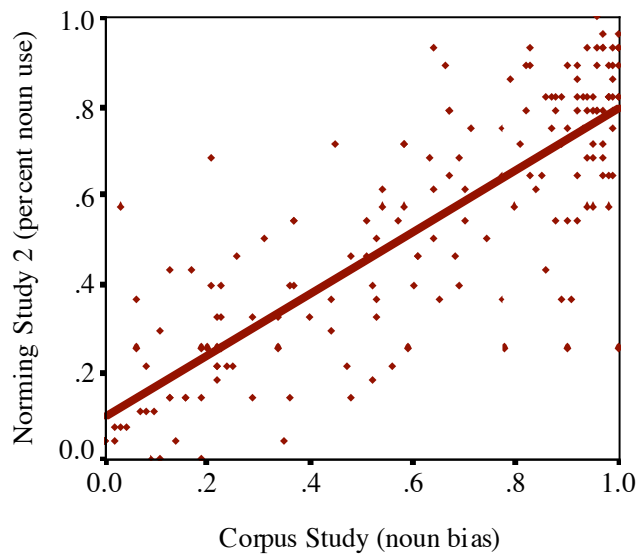


Figure 3. The correlation between the data from Norming Study 2 and the data from the Corpus Study.

5. Experiments 1 and 2

As discussed above, if lexical information guides interpretation independent of syntax, then a word with a dominant noun interpretation should be read slowly in a syntactic context biased to expect a verb (e.g., following the infinitival marker *to*), and a word with a dominant verb interpretation should be read slowly in a syntactic context biased to expect a noun (e.g., following a determiner like *the*), reflecting the competition between the two interpretations of the word when the information sources are in direct conflict. Experiment 1 uses minimal syntactic contexts in a modified lexical decision paradigm to test these predictions, and Experiment 2 uses sentential contexts in a self-paced reading paradigm.

In both experiments we decided not to use unambiguous controls, matched in frequency to the subordinate reading, and rather to directly compare the processing of category-ambiguous words – ranging in lexical biases (in Experiment 1) or sampled from the ends of the distribution (in Experiment 2) – in different syntactic contexts. The rationale for not including unambiguous controls was two-fold. First, given the lexico-semantic complexity of many noun-verb ambiguous words in English, it is unclear what the unambiguous controls for the subordinate category meaning should be matched to in terms of frequency (and other nuisance variables). In particular, as discussed above, in addition to the category ambiguity between a noun and a verb reading, most words – in our set and more generally – have many different senses for both the noun and the verb reading. As a result, especially in paradigms with minimal syntactic contexts where there is little control over which sense(s) will be retrieved by the comprehender, it is far from obvious what a proper set of unambiguous controls would look like. Consequently, the results may be difficult to interpret.

Second, as discussed in the Introduction, some of the earlier results in the literature strongly suggest that the subordinate bias effect reflects interference from the word's dominant category reading, rather than the difficulty of accessing a low-frequency (subordinate) reading. In particular, Tabor et al. (1997) and Gibson (2006) observed a subordinate bias effect for the category-ambiguous word *that* in the determiner context, relative to unambiguous controls like *those* and *this*. Furthermore, Thierry et al. (2008) observed a Left Anterior Negativity (LAN) and a P600 in cases where a word was used in a syntactic context that was inconsistent with the word's dominant category reading, suggesting difficulty in integrating the incoming word into the preceding syntactic context. If it were the case that the subordinate bias effect was due to the difficulty of accessing a low-frequency meaning, then an N400 component should instead have been observed, which has been shown to be sensitive to lexical frequency, with lower-frequency words eliciting larger N400s (e.g., Van Petten & Kutas, 1990, 1991; Van Petten, 1993).

As a result, we focused on including a large set of noun-verb ambiguous words – normed carefully for category biases – in order to seek stronger evidence for a subordinate bias effect in a productive category ambiguity in English (cf. Boland & Blodgett, 2001; Folk & Morris, 2003).

5.1. Experiment 1

The logic of this experiment relies on the assumption that the lexical decision speed may be affected by the context in which the word appears (e.g., Swinney, 1979; Tanenhaus et al., 1979).

Methods

Participants Sixty-three participants from MIT and the surrounding community took part in the experiment. All were between the ages of 18 and 40, native speakers of English and naïve as to the purposes of the study. Participants were paid for their participation. None participated in either of the Norming Studies.

Design and Materials The experiment had a 3 x 3 factorial design crossing (1) lexical bias (Noun, Verb, Equi), and (2) context (Noun, Verb, Null). As described above, based on the results of Norming Study 1, 180 noun-verb ambiguous items were selected from the original set of 240 items: 60 Noun-biased items (e.g., *air*, *corner*, *key*, *table*), 60 Verb-biased items (e.g., *build*, *cut*, *make*, *wait*) and 60 Equi-biased items (e.g., *plan*, *test*, *joke*, *hug*; for a complete list of materials, see Appendix A; the norms are available from the authors upon request).

In addition to the 180 experimental materials, 180 pronounceable non-word fillers were included. The fillers were generated using the ARC Nonword Database (Rastle et al., 2002; available at <http://www.maccs.mq.edu.au/~nwdb/>) and were matched for length in letters with the experimental materials ($p=.97$).

Procedure The participants were told that they would be presented with a series of letter-strings and they would be asked to decide as quickly as possible whether each letter-string was a real word of English or not. They were told to indicate their decision by pressing one of two buttons. The participants were further told that on some trials the words / letter-strings would appear with a determiner (e.g., *the*) or a verb-particle (e.g., *to*). They were instructed to ignore the determiner/particle and make the word/non-word decision based on the letter-string appearing after the determiner/particle. Each trial started with a fixation cross appearing in the

middle of the screen. Participants were told to press the spacebar to begin the trial. After the button-press, a blank screen appeared for 1,000 ms, followed by the stimulus presented for 400 ms, followed again by a blank screen. Participants were told to press one of two buttons to indicate whether they thought the letter-string they saw was a real word of English or not. After the button press, the next trial began. The experiment used the Linger 2.94 software written by Doug Rohde (available at <http://tedlab.mit.edu/~dr/linger>). The order of trials was randomized for each participant. The experiment took approximately 35 minutes to complete.

Results

Accuracy data Across the nine conditions, participants answered correctly 96.5% of the time. There were no effects or interactions in the accuracy data ($F_s < 1.5$). Table 1 presents the mean accuracies across the nine conditions of Experiment 1.

<u>Context</u>	<u>Lexical Bias</u>		
	Noun-biased	Verb-biased	Equi-biased
Noun context	96.7 (0.7)	95.8 (0.7)	96.3 (0.7)
Verb context	96.3 (0.6)	97.0 (0.7)	97.2 (0.5)
Null context	96.9 (0.6)	96.2 (0.6)	95.8 (0.7)

Table 1. Accuracies in percent correct, as a function of lexical bias and context across the nine conditions of Experiment 1 (standard errors in parentheses).

Reaction time data Across the nine conditions, the mean reaction time (RT) was 744 ms. In the analyses presented below we only included the trials on which the word/non-word decision was made correctly. The data patterns were similar in the analyses of all the trials. Reaction time data points that were more than three standard deviations away from the mean RT within a condition were excluded from the analysis, affecting 1.42% of the data. Figure 4 presents the mean RTs across the nine conditions of Experiment 1.

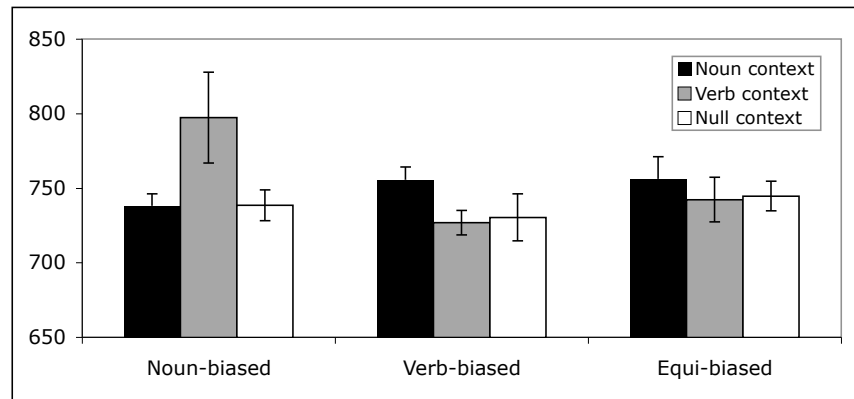


Figure 4. Reaction times as a function of lexical bias and context across the nine conditions of Experiment 1. The error bars represent standard errors of the mean.

A 3 x 3 ANOVA crossing lexical bias (noun-/verb-/equi-) with context (noun-/verb-/null) revealed a significant interaction between the two factors ($F(2,248)=5.45$; $MSe=29720$; $p < .001$). (Note that because lexical bias is a between-items factor, the analysis by items is not meaningful in this design.) This interaction results from the fact that noun-biased items took

participants longer to respond to in the verb-context condition (784 ms), compared to the noun-context (735 ms) or the null-context (737 ms) conditions, and verb-biased items took participants longer to respond to in the noun-context condition (755 ms), compared to the verb-context (724 ms) or the null-context (726 ms) conditions. Note that for both noun-biased and verb-biased items the RTs for the null-context conditions were very similar to the RTs for the congruent conditions, suggesting that in the null context participants interpreted the ambiguous word in its more frequent category. An alternative possibility for why no facilitation was observed for the noun-biased items in the noun context relative to the noun-biased items in the null context (or for verb-biased items in the verb context relative to the verb-biased items in the null context) is that in the noun and verb context materials consisted of two words, whereas in the null context they consisted of only a single word. As a result, it is possible that the facilitation that would have been observed due to the match between the dominant reading and the context, compared to cases with no context, was counteracted by the differences in the length of the materials in the noun/verb context compared to the null context conditions.

The analysis also revealed an unpredicted main effect of bias such that across the different contexts, the verb-biased items were processed faster than the equi-biased items and the noun-biased items. This difference may have resulted from a variety of factors that have been shown to affect word-level processing but were not controlled across the three bias groups (e.g., overall lexical frequency, length, familiarity, imageability, concreteness, age of acquisition, etc.).

Regression analysis In addition to the analysis of variance, we performed a mixed-effects regression analysis (Gelman & Hill, 2006; Baayen, 2008) on the log reaction times using subjects and items as random effects. Following Boland & Blodgett (2001), we used the difference between the noun-reading

log frequency and the verb-reading log frequency values as an independent variable (Log N Freq – Log V Freq), as well as syntactic context. The regression also controlled for word length and log overall frequency.

Only correct responses were analyzed, and data points more than three standard deviations from the mean response time per context condition were removed, accounting for 5% of the data. Analyses were carried out using the R statistical programming language with the packages lme4 (Bates, 2005) and languageR (Baayen, 2008). Significance values were computed using Markov chain Monte Carlo method, and sampling was run for 50,000 steps.

The regression was structured to test for an interaction between lexical bias and syntactic context to evaluate the research question. In particular, since a positive lexical bias indicates a noun-biased word, positive lexical biases should increase reaction times in verb contexts. In contrast, negative lexical biases should increase reaction times in noun contexts. All coefficients were standardized. The fixed effects from the regression analysis are shown in Table 2.

<u>Regression Term</u>	<u>Estimate</u>	<u>Standard Error</u>	<u>t value</u>	<u>p-value</u>
(Intercept)	6.556322	0.026678	245.75	0.000
NounContext	0.021824	0.006358	3.43	0.001
VerbContext	0.015628	0.006349	2.46	0.013
LogOverallFreq	-0.011251	0.003443	-3.27	0.001
WordLength	0.009106	0.003368	2.70	0.007
NullCont:LexBias	0.003440	0.005019	0.69	0.486
NounCont:LexBias	-0.018858	0.005021	-3.76	0.000
VerbCont:LexBias	0.012082	0.005025	2.40	0.017

Table 2. Fixed effects in a mixed model regressing log lexical decision reaction times on context and lexical bias. (Following R notation, interaction terms are denoted using colons.)

Consistent with the hypothesis that lexical information can guide interpretation independent of syntax, these results show the effects in the interaction terms. First, the coefficient of NounContext:LexicalBias is significantly negative ($p < .001$), indicating that a positive lexical bias decreases reaction times in noun contexts, and a negative lexical bias increases reaction times. Second, the coefficient of

VerbContext:LexicalBias is significantly positive ($p < .02$), indicating the opposite pattern for verb contexts. The coefficient of NullContext:LexicalBias is not significant ($p > 0.48$), indicating that in null contexts, lexical bias did not affect reaction times. In addition, the regression shows significant effects of log overall word frequency and length: more frequent words are read more quickly and longer words are read more slowly. Finally, the regression shows significant main effects of NounContext ($p < 0.005$) and VerbContext ($p < 0.02$), indicating that words in these conditions are responded to slower than in the null-context condition.

Discussion

The ANOVA results of Experiment 1 demonstrated that there is some difficulty associated with processing noun-biased words in a verb context and with processing verb-biased words in a noun context. Furthermore, the regression results demonstrated that this difficulty is modulated by the degree of lexical bias, across the 180 items in the experiment. This pattern of results is as predicted by the hypothesis that lexical information can guide interpretation independent of syntax, but not by the hypothesis whereby lexical access is filtered according to the syntactic context.

5.2. Experiment 2

This experiment was conducted to extend the findings from Experiment 1 to a more natural language comprehension task where the critical words were presented in larger syntactic contexts.

Methods

Participants Twenty-four participants from MIT and the surrounding community took part in the experiment. All were between the ages of 18 and

40 years old, native speakers of English, and naïve as to the purposes of the study. None participated in either of the two Norming Studies or in Experiment 1. All participants were paid for their participation.

Design and Materials This experiment had a 2 x 2 design crossing (1) lexical bias (Noun, Verb), and (2) context (Noun, Verb). A subset of the items used in Experiment 1 was used: 24 Noun-biased items and 24 Verb-biased items, for a total of 48 items. The experimental sentences were constructed such that the noun-context and the verb-context conditions were minimally different prior to the critical ambiguous word, by including sentence initial phrases like *NAME had/wanted/needed a/to*. In a small subset of items it was possible to have the regions following the ambiguous word be identical across the two contexts (as in (5)). However, in the majority of items this was not possible without sacrificing plausibility. To minimize the differences in the materials following the ambiguous word and to allow the comparison on the post-ambiguous-word region across the two contexts, the materials were constructed such that the two words after the ambiguous word were always function words (as in (6)).

(5a) Noun context: Mary had a *look* at the documents...

(5b) Verb context: Mary had to *look* at the documents...

(6a) Noun context: Larry had a *bet* with a friend...

(6b) Verb context: Larry had to *bet* on the outcome...

Because many of the ambiguous words were short and because it is often difficult to see the effects on a single word in sentence processing, we

defined three critical regions: (1) the ambiguous word, (2) the word immediately following the ambiguous word, and (3) the word two words after the ambiguous word.

In addition to the 48 target items, 96 filler materials were constructed. The filler sentences used constructions similar to those used in the target items (i.e. NP had/wanted/needed a/to) but used unambiguous nouns and verbs (e.g., *Arnold wanted a sweatshirt with MIT written on it and so he went to the university gift shop; Karen planned to confess to the crime but her lawyer was advising against it.*)

Procedure The task was self-paced word-by-word reading with a moving-window display (Just, Carpenter & Woolley, 1982). The experiment was run using the Linger 2.94 software. Each trial began with a series of dashes marking the length and position of the words in the sentence. Participants pressed the spacebar to reveal each word of the sentence. As each new word appeared, the preceding word disappeared. The amount of time the participant spent reading each word was recorded as the time between key-presses.

To make sure the participants read the sentences for meaning, at the end of each trial a comprehension question appeared asking about the propositional content of the sentence they just read. Participants pressed one of two keys to respond “Yes” or “No”. After an incorrect answer, the word “INCORRECT” flashed briefly. Before the experiment started, a short list of practice items and questions was presented in order to familiarize the participants with the task.

Participants took approximately 35 minutes to complete the experiment.

Results

Accuracy data Across the four conditions, participants answered correctly 95.4% of the time. A 2 x 2 ANOVA crossing lexical bias (noun-/verb-) with context (noun-/verb) revealed an unpredicted effect of context, such that the verb-context conditions were less accurate than the noun-context conditions ($F(1,23)=4.70$; $MSe=209$; $p<.05$). (As in Experiment 1, because lexical bias is a between-items factor, the analysis by items is not meaningful in this design.) There was also an unpredicted marginal effect of bias, such that participants were less accurate in the noun-biased conditions than the verb-biased conditions ($F(1,23)=3.87$; $MSe=88$; $p=.06$), and a marginal interaction ($F(1,23)=3.06$; $MSe=88$; $p=.09$). These effects appear to be driven by the noun-biased/verb-context condition being less accurate than the other three conditions. One possible explanation for the difference among conditions is that the noun-biased words were more biased than the verb-biased words: specifically, the noun-biased words had an average bias of .94 and the verb-biased words had an average bias of .83. The higher bias in the noun-biased conditions combined with the incongruent syntactic context may have resulted in the noun-biased/verb-context condition being less accurate than the other three conditions. Table 3 presents the mean accuracies across the four conditions of Experiment 2.

<u>Context</u>	<u>Lexical Bias</u>	
	Noun-biased	Verb-biased
Noun context	96.9 (.84)	96.9 (1.1)
Verb context	92.0 (1.5)	95.8 (1.3)

Table 3. Accuracies in percent correct, as a function of lexical bias and context across the four conditions of Experiment 2 (standard errors in parentheses).

Reading time data A 2 x 2 ANOVA crossing lexical bias (noun-/verb-) with context (noun-/verb-) was conducted on different regions of the sentence as shown in 7 (the three critical regions are in bold).

(7) Mary had a/to | **look** | **at** | **the** | documents | before the | meeting with the board members.

At the first region (*Mary had a/to*), there were no significant effects ($F_s < 1$). At the ambiguous word there was only a marginal effect of lexical bias, such that the verb-biased items were read faster (267 ms) than the noun-biased items (281 ms) ($F(1,23)=3.83$, $MSe=4818$, $p=.063$). This difference may have resulted from a variety of factors that have been shown to affect word-level processing but were not controlled across the two bias groups. At the word immediately following the ambiguous word, the ANOVA revealed a significant interaction between the two factors ($F(1,23)=5.36$; $MSe=3699$; $p < .05$). This interaction results from the fact that the noun-biased items took the participants longer to read in the verb-context condition (277 ms), compared to the noun-context condition (266 ms), and the verb-biased items took the participants longer to read in the noun-context condition (275 ms), compared to the verb-context condition (260 ms) (see Figure 5). A similar interaction is observed during the following region (the second word following the critical ambiguous word) ($F(1,23)=13.06$; $MSe=9021$; $p < .002$): the noun-biased items took the

participants longer to read to in the verb-context condition (291 ms), compared to the noun-context condition (266 ms), and the verb-biased items took the participants longer to read in the noun-context condition (273 ms), compared to the verb-context condition (260 ms) (see Figure 5).

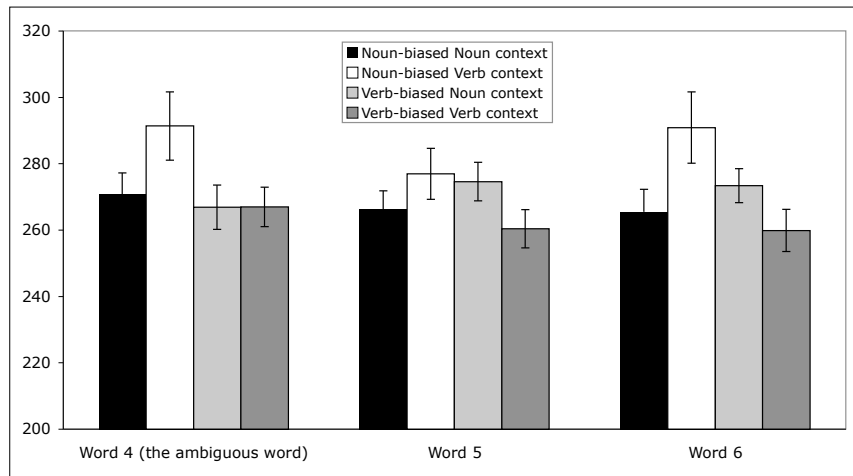


Figure 5. Reading times at the ambiguous word and the two following words as a function of lexical bias and context in Experiment 2. The error bars represent standard errors of the mean.

We don't report comparisons involving later regions in the sentences, because differences in materials across the different conditions make any potential differences hard to interpret.

Regression analysis As in Experiment 1, we performed a mixed effect regression analysis on the log reading times using subjects and items as

random effects and controlling for log overall frequency and length of the critical word. All coefficients were standardized. We used total reading time on the two words following the critical word as the dependent variable. Analyses were carried out using the R statistical programming language with the packages lme4 (Bates, 2005) and languageR (Baayen, 2008). As in Experiment 1, significance values were computed using Markov chain Monte Carlo method, and sampling was run for 50,000 steps.

As in Experiment 1, we tested for an interaction between lexical bias and syntactic context. The hypothesis whereby lexical information guides interpretation independent of syntactic information predicts that the interaction term NounContext:LexicalBias would be negative, and the interaction term VerbContext:LexicalBias would be positive. This corresponds to positive lexical biases (noun-biased words) slowing reading times in verb contexts, and to negative lexical biases (verb-biased words) slowing reading times in noun contexts. The fixed effects from the regression analysis are shown in Table 4.

<u>Regression Term</u>	<u>Coefficient</u>	<u>Standard Error</u>	<u>t value</u>	<u>p-value</u>
(Intercept)	6.225421	0.057197	108.84	0.000
VerbContext	-0.004625	0.013724	-0.34	0.736
LogOverallFreq	0.011882	0.008235	1.44	0.149
WordLength	0.014131	0.007237	1.95	0.051
NounCont:LexBias	-0.009467	0.010639	-0.89	0.374
VerbCont:LexBias	0.029584	0.010639	2.78	0.006

Table 4. Fixed effects in a mixed model regressing log reading times on context and lexical bias.

Consistent with the hypothesis that lexical information can guide interpretation independent of syntax, the coefficient of VerbContext:LexicalBias is significantly positive ($p < 0.01$), indicating that a positive lexical bias increases reading times in verb contexts, and a negative lexical bias decreases reading times. However, although the coefficient of the NounContext:LexicalBias interaction term is in the direction predicted by the hypothesis that lexical information can guide interpretation (negative), it is not significantly different from zero ($p > 0.37$). This may result from the smaller number of subjects and items in this experiment, compared to Experiment 1.

Discussion

The ANOVA results of Experiment 2 demonstrated that in sentential contexts there is some difficulty associated with processing noun-biased words in a verb context and with processing verb-biased words in a noun context providing further support for the hypothesis that lexical information can guide interpretation independent of syntax. Furthermore, similar to Experiment 1, the regression results demonstrated that this difficulty is modulated by the degree of lexical bias. The fact that the regression results were only significant for the verb-context conditions (unlike in Experiment 1, where the regression results were consistent in both the noun- and verb-context conditions) can perhaps be explained by: (a) the fact that there were only 48 items in this experiment as compared to 180 in Experiment 1, resulting in a less powerful analysis; and (b) the fact that the noun-biased words were more biased than the verb-biased verbs, with the possible consequence that the verb-biased items may not have resulted in as much difficulty in the noun contexts as the noun-biased verbs in the verb contexts.

Overall, the pattern of results is similar to the pattern of results in Experiment 1, and is as predicted by the hypothesis that lexical information can guide interpretation independent of syntax, but not by the hypothesis whereby lexical access is filtered according to the syntactic context.

6. Summary and conclusions

Two experiments were presented – a lexical decision experiment and a self-paced reading experiment – that tested the independence of syntactic and lexical information sources in online language processing. Both experiments provided evidence that syntactic and lexical information guide interpretation independently. In particular, both experiments showed a subordinate bias

effect (Duffy et al., 1988; Rayner et al., 1994), such that the dominant lexical meaning was highly available due to its frequency, and the subordinate meaning was made available by the syntactic context, giving rise to elevated RTs for the noun-biased words in a verb context and verb-biased words in a noun context. Furthermore, this set of results generalizes earlier findings from the category-ambiguous word *that* (Tabor et al., 1997; Gibson, 2006) to a productive syntactic-category ambiguity.

The current results thus fill the gap in the literature for processing category-ambiguous words in biasing contexts, using a reading paradigm. These results provide further evidence against syntactic information being the only source of information that can guide sentence processing. Like context (Altmann & Kamide, 1999; Grodner, Gibson & Watson, 2005) and semantic and plausibility information (Kuperberg et al., 2003; Kim & Osterhout, 2005), lexical information can also guide sentence processing, independent of the syntactic context (Tyler & Marslen-Wilson, 1977; Ford, Bresnan & Kaplan, 1982; Marslen-Wilson & Tyler, 1987; Culicover & Jackendoff, 2005).

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Appendix A: Materials used in Experiment 1

NOUN-BIASED	EQUI-BIASED	VERB-BIASED
ADDRESS	ANSWER	ACT
AGE	APPROACH	ATTACK
AIR	BLOCK	BET
AMOUNT	CAMP	BUILD
ARM	CHALLENGE	CALL
BAG	CHANGE	CAUSE
BANK	CLIP	CLAIM
BOARD	COST	CLICK
BOOK	COVER	CONCENTRATE
BORDER	DESIGN	CONTACT
BOTTLE	DRESS	CONTROL
BOX	FIGHT	COOK
BRIDGE	FILE	CROSS
BUDGET	FILM	CUT
CAGE	GROUP	DANCE
CARD	HELP	DREAM
CASE	HUG	DROP
CHAIR	JOKE	EXERCISE
CHART	JUDGE	FEAR
CLOUD	LIE	FIND
CLUB	LOAD	FIT
COIN	MAIL	FLOW
COLOR	MARK	FORM
CONDITION	MODEL	GAIN
CORNER	MURDER	HANDLE
COUPLE	NOTE	HONOR
DISTANCE	OFFER	INCREASE
DOG	PARK	JUMP
DUCK	PHONE	LAUGH
DUST	PHOTOGRAPH	LOCK
EYE	PLACE	LOOK
FARM	PLAN	MAKE
FATHER	POINT	MISS
FAVOR	POST	MOVE
FERRET	PROGRAM	NOTICE
FLAG	REPORT	PLAY
FLOOR	RESULT	PRINT
GROUND	RING	PULL
HEAD	RULE	REST
HOUSE	SENSE	RETURN
IMAGE	SHARE	RUN
KEY	SHIP	RUSH
MAN	SHOW	SAY
NETWORK	SIGNAL	SEARCH

NUMBER	SIN	SMILE
POLICE	SINK	SPIN
POSITION	SMOKE	STAND
POSTER	STEP	STAPLE
PRICE	STRESS	START
RESEARCH	STRIKE	STUDY
SHAPE	TAPE	TAKE
SILENCE	TAX	TALK
STAFF	TEST	TOUCH
STONE	TIE	TRADE
STYLE	TOUR	TRUST
TABLE	TRAIN	TWIST
TRAFFIC	TYPE	USE
TRUCK	UPDATE	VOTE
WALLPAPER	VIEW	WAIT
WIRE	WAVE	WORRY

Appendix B: Materials used in Experiment 2

Verb-biased items

- (1) Mary had a look at the documents before the meeting with the board members.
Mary had to look at the documents before the meeting with the board members.
- (2) Wallace planned a move to the East coast after graduating from college in the spring.
Wallace planned to move to the East coast after graduating from college in the spring.
- (3) Barbara had a call from a friend after she came home from work.
Barbara had to call one of her friends after she came home from work.
- (4) David had a laugh during the show because it was quite hilarious.
David had to laugh during the show because it was quite hilarious.
- (5) Jim wanted a say in the matter but the manager kept interrupting him.
Jim wanted to say that he was sorry, but the manager kept interrupting him.

- (6) Melissa continued the wait for a green card but she knew that it may take a couple of years.
Melissa continued to wait for a green card but she knew that it may take a couple of years.
- (7) George had a worry about his son who was having behavioral problems at school.
George had to worry about his son who was having behavioral problems at school.
- (8) Jason continued the talk about the new theory of visual attention in primates.
Jason continued to talk about the new theory of visual attention in primates.
- (9) Peter had a use for the old piano, and so he decided to keep it.
Peter had to use all his savings to buy a plane ticket to Europe.
- (10) Nathan listed the make of all the automobiles that were being presented at the Auto Show.
Nathan wanted to make one more attempt at solving the physics problem before he gave up.
- (11) Lindsey wanted some trust from her partner, and she talked openly about it.
Lindsey wanted to trust all her colleagues, but she knew that some of them weren't very trustworthy.
- (12) Larry had a bet with a friend that he would get married last.
Larry had to bet on the outcome of the game, because he wanted to make some money.
- (13) Daniel hoped for a jump in the ratings after the TV show, but he was disappointed.
Daniel hoped to jump on the trampoline but his parents wouldn't let him.
- (14) Ted wanted a share of the profits but the CEO didn't think he deserved it.
Ted wanted to share all the profits but the CEO disagreed vehemently.
- (15) Jessica was a find for the band because of her beautiful voice.

- Jessica wanted to find some more articles about the onset of Alzheimer's for her research paper.
- (16) Stewart had the build of a football player, and many girls found him attractive.
Stewart had to build one more robot for his engineering class, and he was excited.
- (17) Jerry had a take on the scandal that no one else in the office shared.
Jerry had to take two more classes in order to graduate, and so he signed up for astronomy and art history.
- (18) Zach had a drop of the solution in the test-tube, and he was waiting for the chemical reaction to happen.
Zach had to drop all his books on the floor as he rushed to pick up the phone.
- (19) Carolyn liked the play at the theater, and so she bought tickets for another performance.
Carolyn liked to play on the computer, but her Mom tried to make her read more books.
- (20) William wanted the vote from the middle-class, and so he worked hard on his campaign.
William wanted to vote for the democratic candidate, but he was really disappointed with his views on religion.
- (21) Denise wanted an increase in his salary this month, and so he talked to his boss.
Denise wanted to increase some of the programmers' salaries, but she needed the CEO's approval.
- (22) Michael had a cut on his leg from the bike accident, and so he put on a bandage.
Michael had to cut all the tomatoes for the salad, but he couldn't find the cutting board.
- (23) Jake wanted a print of the art-work from the museum, and so he went to the museum gift-shop.
Jake wanted to print some of the documents before the meeting, but the printer was broken.

- (24) Norman had a run in the morning and he felt very energized and refreshed afterwards.
Norman had to run to the store to get some groceries after picking up his son from school.

Noun-biased items

- (1) Katie needed a table for her new apartment, and so she went to the nearby furniture store.
Katie needed to table one more proposal before the meeting, but she kept getting distracted.
- (2) Steve had a chair in his office which was a valuable antique item.
Steve had to chair some of the meetings this month because the CEO was away in London.
- (3) Timothy was a father of three boys, and he was very happy in his family life.
Timothy wanted to father one more child with his wife, but she couldn't get pregnant.
- (4) Rebecca wanted the wallpaper in the bedroom to match the style of the furniture.
Rebecca wanted to wallpaper all the rooms in her new apartment, but she couldn't decide on the color.
- (5) Clay liked the air in the mountains, because it was very fresh and helped his asthma.
Clay wanted to air some of the footage from the war zone, but the network owners didn't allow it.
- (6) Kyle liked the book about the Cold War, and so he recommended it to his father.
Kyle liked to book all his flights in advance, because he hated doing things in the last minute.
- (7) Natalie had a number on her ticket but she couldn't figure out whether it referred to the row or to the section.
Natalie had to number all the pages in the manuscript before submitting it to the publishers.

- (8) Brenda had a bag that was full of groceries on her way home from the supermarket.
Brenda had to bag all the groceries at the supermarket, because the other employees were on holiday.
- (9) Sabrina needed some distance from her ex-boyfriend after they broke up last month.
Sabrina needed to distance herself from her ex-boyfriend after they broke up last month.
- (10) Jack wanted a place by the ocean, and so he looked through the real estate magazine.
Jack wanted to place one of the orders over the phone, and so he called up the company.
- (11) Mitchell liked the joke about the senator, but his friends got tired of it eventually.
Mitchell liked to joke about the senator, but his friends got tired of it eventually.
- (12) Linda needed a cage for her rabbit, and so she went to the pet store.
Linda needed to cage all her rabbits, because she was expecting some visitors.
- (13) Martin had a card on his desk, which somebody sent him from Hawaii.
Martin had to card all the attendees, because the club had very strict rules.
- (14) Becca needed the price of the jacket, and so she asked the sales associate.
Becca needed to price some of the new items, and so she checked the price-list.
- (15) Garry wanted a position in the company and so he sent his resume to human resources.
Garry wanted to position two of the armchairs in the living room, but his decorator disagreed.
- (16) Henry liked the view from his window at the hotel where he was staying.

- Henry liked to view some of the old family albums when he was feeling nostalgic.
- (17) Ryan liked the silence of an empty house when he was writing his novels.
Ryan wanted to silence the two noisy children at the restaurant, and so he gave them some toys.
- (18) Eric wanted a box for his documents because his desk was getting too messy.
Eric wanted to box all his documents because his desk was getting too messy.
- (19) Emma wanted a tour of the city on her trip to Madrid in the spring.
Emma wanted to tour some of the oldest cities in Europe on her trip.
- (20) Miranda wanted the head of the department to organize a conference on brain research.
Miranda wanted to head in the direction of the city park, but didn't really know her way.
- (21) Albert wanted a key to the building, and so he contacted the administrator.
Albert wanted to key in on the answer during the exam, but was failing miserably.
- (22) Sarah needed the staff to be around during the weekend because of the conference.
Sarah needed to staff all the desks during the weekend because of the conference.
- (23) Walter had a truck in his garage, but he very rarely used it.
Walter had to truck a few boxes from his office to his home.
- (24) Luke had a poster on the wall with a picture of a famous body-builder.
Luke had to poster all over campus to attract new members to the hiking club.