Effects of a word's status as a predictable phrasal head on lexical decision and eye movements.

EFFECTS OF A WORD'S STATUS AS A PREDICTABLE PHRASAL HEAD ON LEXICAL DECISION AND EYE MOVEMENTS

A Thesis Presented

by

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Each of my committee members made tangible and distinct contributions to this project. When I first speculated about the possible role of syntactic category predictability, Lyn Frazier immediately steered me toward the right part of the literature. She has since pressed me to think carefully about the theoretical alternatives in this domain. At several points, Keith Rayner emphasized potentially critical methodological and theoretical issues. And throughout this project, Chuck Clifton has been invaluable in helping me refine my theories and my experiments, and my understanding of the relation between the two. He has been infinitely generous with his time and wisdom.

My wife, Sheri Kurtz, and my daughter Vera have actually listened to dinner-table discussion (or rather, monologue) about why the parser might predict phrasal heads. This is time they will never get back. Sorry, and thanks.

ABSTRACT

EFFECTS OF A WORD'S STATUS AS A PREDICTABLE PHRASAL HEAD ON LEXICAL DECISION AND EYE MOVEMENTS

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Three lexical decision and two eyetracking experiments replicated and extended Wright and Garrett's (1984) finding of faster lexical processing for predictable phrasal heads. In both experimental paradigms, nouns were processed more quickly than adjectives following a determiner, with the target words matched on other lexical variables. In the lexical decision paradigm, RT to a head noun was faster following an adjective or a determiner than following a nominal modifier; in the eyetracking paradigm, the interpretation of this comparison was complicated by the likely presence of spillover effects. In the lexical decision paradigm, RT was faster to an adjective following a degree adverb than following a determiner; in eyetracking, the degree adverb speeded reading of the noun that followed the adjective. The pattern of results suggests that the effect of a word's status as a predictable head is due to inhibition, not facilitation. The results are interpreted in relation to Wright and Garrett's hypothesis that the parser actively predicts obligatory phrasal heads.

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CHAPTER 1

LEXICAL PROCESSING AND SYNTACTIC CONTEXT

Introduction

Consider a sentence that begins as in (1):

(1) After finishing his meal, John tasted the…

The determiner *the* that ends this fragment marks the beginning of a noun phrase (NP)[1], and the grammar of English requires that this noun phrase have a head. If the sentence continues as in (2), this requirement is immediately satisfied:

(2) After finishing his meal, John tasted the watermelon…

On the other hand, the sentence can also continue with an adjective, as in (3):

(3) After finishing his meal, John tasted the ripe…

The adjective *ripe* does not satisfy any syntactic requirement; an adjective is a legal, but optional, continuation of the sentence. However, an adjective can indeed be required in a sentence continuation, as it is after (4):

(4) After finishing his meal, John tasted the very…

Conversely, a noun can appear in a position in which it does not satisfy any pre-existing syntactic requirement; e.g., an additional noun can appear at the end of (2), as in (5):

(5) After finishing his meal, John tasted the watermelon sherbet…

This thesis presents five experiments that were designed to investigate the question of whether lexical processing is affected by the syntactic requirements instantiated by the preceding context. Specifically, these experiments tested the

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[1] Though I accept the DP hypothesis of Abney (1987), I refer to NPs in this thesis because the question of whether determiners are heads is not relevant to the issues addressed here, and because traditional psycholinguistic usage generally refers to NPs.

hypothesis that a word is processed more easily when it is a predictable phrasal head, as is a noun after (1) and an adjective after (4). This introductory chapter first reviews previous research examining the role of syntactic context in lexical processing, then discusses two experiments by Wright and Garrett (1984) that are direct precursors to the experiments that will be presented here. The chapter concludes by motivating and outlining the five experiments that will be described in detail in subsequent chapters.

Syntactic Context Effects on Word Recognition

A substantial body of research has investigated the role of syntactic context in word recognition. Across many experiments using a variety of paradigms, word recognition performance has been shown to vary depending on the word's syntactic congruity with a preceding sentence fragment. In both visual lexical decision (Boland, 1993; O'Seaghda, 1997, West & Stanovich, 1986; Wright & Garrett, 1984) and visual naming tasks (Boland, 1993; O'Seaghda, 1997; Peterson, Burgess, Dell, and Eberhard, 2001; West & Stanovich, 1986), response time (RT) is faster when the target word is a syntactically legal continuation of a preceding sentence fragment than when the target word is an illegal continuation. In addition, identification of a masked target word presented either visually (Potter, Stiefbold, & Moryadas, 1998) or auditorily (Deutsch & Bentin, 1994) is more accurate when the target is a syntactically legal continuation.

Several theorists have suggested that the effect of syntactic context on lexical processing may not be an effect on lexical access itself. At a given point in a sentence, the syntactic category of the next word is usually quite unconstrained (Frazier, 1987b), and it would likely prove computationally intractable for the word recognition system to increase the level of activation of all lexical items that are members of the syntactic categories that provide legal continuations (Tanenhaus, Dell, & Carlson, 1987; Tanenhaus and Lucas, 1987). In addition, the results of several cross-modal priming experiments on the processing of words that are ambiguous between noun and verb meanings (e.g., *rose*) have suggested that both meanings are briefly active, even when only one of the two syntactic categories can legally continue the sentence (Seidenberg, Tanenhaus, Leiman, & Bienkowski, 1982; Tanenhaus & Donnenwerth-Nolan, 1984; Tanenhaus, Leiman, & Seidenberg, 1979). These experiments have found speeded lexical decision RT to a semantic associate of the incongruent meaning, if the lexical decision target appears within about 200 ms of the onset of the ambiguous word.

On the other hand, Folk and Morris (2003) conducted two eyetracking experiments suggesting an early locus for the effect of syntactic context on lexical processing. A robust finding from the eye movement literature is the so-called "subordinate bias effect" (Rayner, Pacht, & Duffy, 1994), in which an ambiguous word is read more slowly when the less frequent meaning of the word is selected by the preceding context. Folk and Morris replicated this effect for words whose subordinate meaning and dominant meaning were in the same syntactic category (e.g., *cabinet*), but found that when a word was ambiguous between noun and verb meanings, and only one of these syntactic categories provided a legal continuation of the preceding context, the subordinate bias effect disappeared altogether. This result suggests that in normal reading syntactic context may help to direct access to the lexicon so that a syntactically incongruent meaning is never accessed. It is an open question how the results obtained by Folk and Morris should be reconciled with the cross-modal priming results obtained by Tanenhaus and colleagues (Seidenberg et al., 1982; Tanenhaus & Donnenwerth-Nolan, 1984; Tanenhaus et al., 1979), though it is worth noting that the eyetracking paradigm, due to its naturalness, may be less likely to introduce strategic effects or task demands.

One alternative explanation of the effect of syntactic context on word recognition has emphasized the possible role of methodological artifact (Tanenhaus et al., 1987; Tanenhaus & Lucas, 1987). Early research on this topic was conducted primarily with single-word primes rather than full sentence fragments, and in this paradigm syntactic context effects generally appeared in lexical decision tasks (Carello et al., 1988; Goodman et al., 1981; Katz, Boyce, Goldstein, & Lukatela, 1987; Lukatela et al., 1983; Seidenberg, Waters, Sanders, & Langer, 1984; Sereno, 1991), but failed to appear in naming tasks (Carello et al., 1988; Seidenberg et al., 1984; Sereno, 1991). In addition, only a relatively small effect of syntactic context (compared to semantic context) appeared in an auditory "gating" task (Grosjean, 1980) with a sentence fragment preceding the target word (Tyler & Wessels, 1983). The lexical decision task is thought to be particularly susceptible to decision bias (Forster, 1979; West & Stanovich, 1982), so it appeared initially plausible that decision bias was responsible for the pattern of results. As noted above, however, the effect of syntactic context on word recognition has now been replicated numerous times in a naming task, with the critical difference being that the target word was preceded by a sentence fragment rather than by a single word. In fact, the syntactic context effect in the naming task is sufficiently robust that Peterson et al. (2001) were able to use it to investigate whether idioms such as *kick the bucket* receive a normal syntactic analysis. In addition, Farrar (1998) has obtained a reliable syntactic context effect on naming with a single word prime, with the critical difference that the experimental design encouraged participants to analyze the prime and target word as part of a single sentence.

A second explanation of the syntactic context effect offered by Tanenhaus et al. (1987) and Tanenhaus and Lucas (1987) suggests that participants in word recognition tasks that require an overt response, such as lexical decision and naming, tend to attempt syntactic integration of the target word before making their response. It is possible that responses are slower when the target word is syntactically incongruent with the preceding context because failing to integrate the target word takes longer, on average, than succeeding in integrating the target word. It is less clear how this account would explain effects of syntactic context in those experiments in which the dependent measure is word recognition accuracy, rather than RT (e.g., Deutsch and Bentin, 1994; Potter et al., 1998).

A prediction of this "output editing" account is that the effect of syntactic context should be essentially inhibitory, since it arises from slow RT when the target is syntactically incongruent with the preceding fragment rather than from facilitation when the target is syntactically congruent. The results of an experiment by West and Stanovich (1986, Exp. 4) confirmed this prediction. They found naming RT to be similar when the target word was syntactically congruent with the preceding fragment and when the fragment established a syntactically "neutral" context (*The next word is...*), and faster in both of these conditions than in a syntactically incongruent condition. However, in an auditory lexical decision experiment Deutsch and Bentin (1994, Exp. 1) found both a facilitatory effect of syntactic congruency and an inhibitory effect of syntactic incongruency, compared to a neutral condition; these two effects were of approximately equal size.

In sum, while it is quite clear that syntactic context has a non-artifactual effect on lexical processing, it is not clear whether this is an early effect (i.e., an effect on lexical access), or a late effect (i.e., an effect on processes related to syntactic integration). While theoretical considerations and some empirical evidence would seem to argue in favor of the latter position, both the eyetracking results obtained by Folk and Morris (2003) and the auditory lexical decision results obtained by Deutsch and Bentin (1994) raise questions about this conclusion.

Wright and Garrett (1984)

As the preceding discussion has emphasized, most experiments examining effects of syntactic context on lexical processing have used an experimental manipulation that renders the target word either a grammatical or an ungrammatical continuation of the preceding word or sentence. To take a representative example, Wright and Garrett (1984, Exp. 1) and West and Stanovich (1986) used fragments such as *The man spoke but could* and *Just at the time of*, with the targets *compete* and *entries* appearing after these fragments; *compete* is a grammatical continuation of the first fragment, but an ungrammatical continuation of the second, and conversely for *entries*. It could be argued that this body of research has not addressed the question about syntactic context effects that is arguably of greatest interest, namely, whether syntactic context plays a role in lexical processing in the course of normal language comprehension. Outside of the laboratory, it is quite rare for a sentence to suddenly become ungrammatical in the manner of these materials; what the research has demonstrated is that responses are affected when a word is an ungrammatical continuation of the preceding sentence, but it does not show an effect of normal variation in syntactic context on lexical processing.

Two experiments by Wright and Garrett (1984, Exps. 2 and 4) provide the exceptions to the above generalization. In these experiments, the target word was always a grammatical continuation of the preceding fragment. Because these two experiments provide the starting point of the experiments to be presented here, I describe them in some detail. Participants were presented with a sentence that appeared one word at a time, cumulatively from left to right across a computer screen. One hundred ms after the onset of the final word before the target word, participants heard a brief tone, followed 300 ms later by the onset of a lexical decision target in uppercase letters. The specific target word was not predictable on the basis of the preceding context. The fragment was varied so that in one condition, a word with the target's syntactic category was a phrasal head that was highly predictable based on the preceding context, while in the other condition, the target provided a syntactically legal, but unpredictable, continuation of the sentence. In one of these experiments the target was a noun, while in the other it was an adjective. Examples of the materials are shown below:

(6a) A few strange men devote EXPULSION

(6b) A very large pine forest EXPULSION

(7a) The interesting clock seems very TOLERABLE

(7b) Your visiting friend should enjoy TOLERABLE

In (6a), the verb that concludes the context fragment is strongly transitive-biased, so that a continuation of the sentence would be very likely to contain a direct object NP. While the head of this phrase need not appear as the very next word (in fact, a determiner such as *the* is quite likely to come next), the NP must ultimately have a head. In (6b), on the other hand, the target noun can be attached as the head of a noun-noun compound (e.g., *forest campground*), but the participant has no reason to assume, before reading this word, that the last word of the fragment is the initial constituent of such a compound. (In fact, it is possible that in a sentence like 6b, the parser initially attaches the noun *forest* as the head of the phrase *A very large pine forest*; see Chapter 4.) In (7a), the fragment ends in a degree adverb, which marks the beginning of an adjective phrase; on one syntactic account the degree adverb is in the specifier position of this phrase (Jackendoff, 1977; cf. Abeillé & Godard, 2003). This adjective phrase must have a head. In (7b), the fragment is likely to continue with an NP that is the direct object of the verb that ends the fragment, and this NP can, but need not, include an adjective before the head noun. In both experiments, control conditions were included to ensure that the contextual manipulation did not have a general facilitatory or inhibitory effect on a subsequent target; for example, (7a-b) were accompanied by conditions with nonword targets in place of the adjectives.

In both experiments, lexical decision RT was significantly shorter in the (a) version, in which the target was a predictable phrasal head. In interpreting these results, Wright and Garrett proposed “a predictive mechanism that might either be characterized as ‘search for phrasal heads’ or a top-down prediction of the phrasal categories for which the target words may serve as heads” (p. 39). They emphasized that such a predictive mechanism might, in principle, facilitate lexical access itself. However, the account that they tentatively endorsed suggests, instead, that RT is faster when a word is a predictable phrasal head because of a "confirmation procedure that tested for the satisfaction of the parsing constraints imposed by the predicted phrasal type. Such a procedure might be completed upon the presentation of a phrasal head, but not by presentation of other phrasal elements" (p. 39). In other words, the core of Wright and Garrett's account of their results is the idea discussed above, i.e., that participants cannot help but to engage in a process of syntactic integration before making a response. In commenting on Wright and Garrett's results, Frazier (1987b) noted that "it would certainly be natural to assume that syntactic analysis of an item is performed more rapidly when the item confirms an obligatory syntactic prediction than when it does not" (fn. 7, p. 181). In short, these two experiments can be seen as demonstrating that RT in word recognition tasks is affected not only by whether a word can be integrated syntactically into the preceding context, but also, if the word can in fact be integrated, by whether the word satisfies a structural prediction that was made in advance.

Wright and Garrett's account endorses the view that the human sentence processor makes use of "top-down" parsing strategies (e.g., Crocker, 1994, 1996; Frazier & Fodor, 1978; Gibson, 1998; Johnson-Laird, 1983, chap. 13; Kimball, 1973, 1975; Konieczny, 2000; Schneider, 1999). A top-down parser uses grammatical or probabilistic information to enter nodes in the syntactic representation of the sentence, or *phrase marker*, before receiving the spoken or written input that will ultimately correspond to these nodes. The class of parsers with top-down components includes so-called "left corner" parsers, which use bottom-up information to recognize the initial (or leftmost) constituents of phrases or clauses, but then posit additional structure within the phrase or clause in a top-down manner. A purely bottom-up parser, on the other hand, enters each terminal node in the phrase marker on the basis of lexical input, and enters a higher-level node only after some or all of the node's daughters have been entered.

If the parser does have a top-down component that enables it to build predictable structure in advance of the input, then the process of incremental syntactic attachment (Frazier & Rayner, 1982; Just & Carpenter, 1980) may be facilitated when a word's syntactic category is predictable in advance. If the grammar requires an input word with a particular syntactic category, and the parser uses a top-down strategy to pre-build the corresponding structure, then attaching this word, when it does arrive, will simply be a matter of inserting it into this structure.

As an example, consider how a top-down and a bottom-up parser might each behave when encountering the input in (8):

(8) After the meal, John tasted...

A parser with a top-down component may use the information that the verb *taste* is very likely to appear with a direct object to build, predictively, the structure corresponding to an NP complement for the verb. This will include at least the NP node itself and the daughter node corresponding to the head of this phrase. If a determiner now arrives, as in (1), this determiner can be attached within the NP complement that the parser has already built. When the head noun then arrives, as in (2), the parser will similarly be able to insert this word directly into the pre-built structure. On the other hand, a purely bottom-up parser will not, upon encountering the verb *taste,* build any syntactic structure within the verb phrase beyond the verb itself. It will attach the determiner in (1) by inserting an NP node within the verb phrase and inserting the determiner within this NP, but still, it will not yet build a node corresponding to the NP's head. When the head noun arrives, as in (2), yet another new node will have to be built.

Overview of the Present Research

The experiments presented here had three main goals. The first was to rule out possible artifactual explanations for Wright and Garrett's results. In Wright and Garrett's experiment with noun targets, the noun-noun compounds (e.g., *forest expulsion*, *engine betrayal*, *husband rotation*, *camera growth*) involved implausible, or even anomalous, combinations of concepts (Murphy 1988, 1990). It could be argued that this factor was responsible for the relatively slow RTs on the noun when it was the second constituent in a such a compound. In both lexical decision (Fischler & Bloom, 1979; O'Seaghda, 1989, 1997; Schuberth & Eimas, 1977) and naming experiments (O'Seaghda, 1997; Stanovich & West, 1983) semantically incongruent targets tend to elicit slow RTs. In addition, in both of Wright and Garrett's experiments the fragments that preceded the targets differed much more than was strictly necessary to manipulate the target word's status as a predictable phrasal head. For example, the mere presence or absence of a degree adverb, without any other differences between the sentences, should have been sufficient to manipulate the predictability of an adjective in (7a-b). The irrelevant variation in the context fragments makes it difficult to attribute the effects Wright and Garrett observed to any one source. The present experiments were designed to determine whether adjectives and nouns are each processed more easily when they are predictable phrasal heads, while eliminating the potential confounds in Wright and Garrett's experiments.

The second goal of the experiments presented here was to make cross-categorial comparisons between the processing of adjectives and the processing of nouns. In the typical syntactic environment in which adjectives and nouns appear, i.e., following a determiner, a noun is a predictable phrasal head, while an adjective is not. To the extent that a word's status as a predictable phrasal head makes a processing difference, nouns and adjectives that are matched on factors such as length and frequency should differ in the ease with which they are processed. Somewhat surprisingly, there is no published study in the literature that has made this simple comparison.

Finally, the third goal of the present experiments was to rule out task demands as an explanation for the effects reported by Wright and Garrett. It is possible that the time needed for syntactic integration affects tasks such as lexical decision and naming, which require an overt response, but that syntactic integration makes a negligible contribution to normal linguistic processing, except in certain well-defined circumstances (e.g., garden path sentences). In an attempt to rule out this possibility, each comparison of experimental conditions was conducted not only in a lexical decision paradigm, but also in an eyetracking paradigm. Experiments 1, 2, and 4 used a lexical decision paradigm that was similar, though not identical, to the one employed by Wright and Garrett. In Experiments 3 and 5, the same target words that were used in Experiments 1, 2, and 4 were embedded in full sentences and participants' eye movements were monitored as they read. The two eyetracking experiments may be regarded as providing the strongest test of whether syntactic context influences lexical processing in normal language comprehension, since in this paradigm there is no task-specific output stage at which the experimental manipulation could have an effect. If an effect were to appear in the eyetracking experiments, it would suggest that syntactic context (and more specifically, whether a word is an obligatory phrasal head) affects lexical processing in the absence of any unnatural task demands.

The plan of the remaining chapters is as follows. Chapter 2 presents Experiments 1-3, which used a common set of materials to compare a) the processing of adjectives and nouns following a determiner and b) the processing of nouns following adjectives and following nouns. Chapter 3 presents Experiments 4 and 5, which compared the processing of adjectives following degree adverbs and following determiners. In Chapter 4 the results of the five experiments are discussed further, focusing on implications for theories of syntactic parsing, word recognition, and eye movements in reading.

CHAPTER 2

EXPERIMENTS 1-3

Overview of the Experiments

Experiments 1-3 made use of 31 sentence pairs like the following[2]:

(9a) The supervisor decided that the fancy furniture would no longer be produced.

(9b) The supervisor decided that the porch furniture would no longer be produced.

Each pair of sentences was identical except for the fact that in the (a) version, the subject noun phrase of the embedded *that*-clause contained an adjective-noun combination (*fancy furniture*), while in the (b) version, it contained a noun-noun compound (*porch furniture*). In Experiment 1, the word that differed between conditions (*fancy/porch*) was the target word in a lexical decision task, appearing after participants were presented with the sentence up to this point (*The supervisor decided that the*). At this point in the sentence a noun, but not an adjective, is an obligatory phrasal head. If it is indeed the case that this syntactic property affects lexical decision RT, responses in this experiment should be faster to nouns than to adjectives. In Experiment 2, the word that differed between conditions was included in the pre-target fragment, and the lexical decision target was the subsequent noun (*furniture*). This noun is an obligatory phrasal head following an adjective, as in (9a), but not following a noun, as in (9b), resulting in the prediction of faster RT in (9a). Two other conditions were included in Experiment 2; these are described below. In Experiment 3, participants read the full sentences as their eye movements were monitored. The predictions for this experiment were that *porch* would be read more quickly than

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[2] In fact 32 pairs were constructed, but one pair was excluded from all analyses when it was noted that one of the modifiers (*drawing*) was ambiguous as to syntactic category.

fancy, but *furniture* would be read more quickly when it followed *fancy* than when it followed *porch*. The full set of materials is presented in Appendix A.

In order to make sure that Experiments 1-3 were in fact testing the hypothesis under consideration, the 31 sentence pairs were equated in several ways. First, it was necessary to ensure that the adjectives and nouns that appeared in modifier position did not differ on dimensions such as frequency that are known to affect lexical decision latency and reading time. Second, it was important to rule out differences in lexical predictability (i.e., the predictability of the specific lexical items) between the adjectives and nouns in modifier position. Similarly, it was important to ensure that the choice of modifier did not affect the lexical predictability of the subsequent head noun. Finally, it was necessary to ascertain that both the adjective-noun and noun-noun sentences were relatively plausible, and that they did not differ in plausibility.

The adjective and noun in each pair were matched for length, and overall these adjectives and nouns did not differ significantly in frequency. Frequency data were obtained both from the million-word Brown corpus (Francis & Kučera, 1982) and the 131-million-word HAL Corpus (Burgess & Livesay, 1998). In the Brown corpus, the adjectives had a mean $\log_e$ frequency of 3.98, with $SD = 1.50$, and the nouns had a mean $\log_e$ frequency of 4.42, with $SD = 1.73$. In the HAL corpus, the adjectives had a mean $\log_e$ frequency of 9.74, with $SD = 1.72$, and the nouns had a mean $\log_e$ frequency of 10.02, with $SD = 1.62$. These frequencies were not significantly different ($p = .20$ and $p = .52$, based on the Brown and HAL corpora respectively). The mean raw frequencies in the HAL corpus were 404 per million for the adjectives and 398 per million for the nouns ($p = .97$).

In addition, data made available by the English Lexicon Project (Balota, D.A., Cortese, M.J., Hutchison, K.A., Neely, J.H., Nelson, D., Simpson, G.B., & Treiman, R., 2002) enabled a rough comparison of the lexical decision latencies for these words in isolation. The adjectives and nouns had mean lexical decision latencies of 625 ms (*SD* = 47 ms) and 614 ms (*SD* = 44 ms), respectively. Though this numerical difference is in the direction of the hypothesis under consideration (i.e., longer RT to adjectives than to nouns), it does not approach statistical significance ($p = .35$). In addition, the numerical difference was largely generated by two reaction time outliers, one in each direction. The adjective *newest* had a mean lexical decision latency of 738 ms, which was 2.57 standard deviations above the overall mean of 620 ms, while the noun *house* had a mean lexical decision latency of 494 ms, which was 2.75 standard deviations below this overall mean. If these two outliers are excluded, the difference in the mean RTs for the adjectives and nouns is reduced from 11 ms to 3 ms. Finally, it is worth noting that though the English Lexicon Project data are useful for ensuring that the null hypothesis of no difference between the two groups of words is not clearly violated, more fine-grained inferences from between-item comparisons may be tenuous, since these data are gathered from multiple experiments with different participants. The effect of this limitation is seen, for example, in the fact that for the adjectives and nouns in the present experiments the correlation between lexical decision and naming times was $r = .320$, based on the English Lexicon Project data; by comparison, Schilling, Rayner, and Chumbley (1998) obtained a correlation of $r = .833$ between item lexical decision and naming times in a within-participants design.

A sentence continuation norming study ($N = 17$) was used to confirm that the specific adjectives and nouns that differed between conditions were unpredictable in context. For each of the 31 context fragments, each participant was asked to write the first word that came to mind as the next word in the sentence. Out of a total of 527 trials, on only three occasions did a participant continue the fragment with one of the target words. Participants continued the fragment with a noun on 523 of 527 trials.

Both the adjective-noun combinations (e.g., *fancy furniture*) and noun-noun compounds (e.g., *porch furniture*) were intended to be non-lexicalized (i.e., not highly frequent or idiomatic), but also easily comprehensible. A search of the Brown Corpus did not reveal any instances of the adjective-noun or noun-noun sequences, confirming that these were not frequent expressions. In addition, a second sentence continuation norming study ($N = 20$) was conducted in which participants were provided with the fragment up through the initial adjective or noun in the two-word sequence, and asked to write the most likely next word. Ten participants provided continuations for each fragment, and in only a single instance did a participant use one of the target words. When the fragment ended with an adjective, participants wrote a noun as the next word over 95% of the time, but when the fragment ended with a noun, they wrote a noun as the next word less than 7% of the time.

Finally, an additional rating study ($N = 20$) was used to assess the plausibility of the sentences. Ten participants rated the plausibility of each sentence on a ten-point scale. The adjective-noun sentences had a mean plausibility of 8.10, $SD = 1.26$, and the noun-noun sentences had a mean plausibility of 7.85, $SD = 1.57$. These ratings did not differ significantly ($p > .4$).

The experimental methods and results are presented below. This is followed by a discussion of the results of all three experiments.

Experiment 1

Method

Participants. The participants were 32 members of the University of Massachusetts community, all of whom received course credit or were paid $5. The participants had normal or corrected-to-normal vision and were native speakers of American English. All participants were naïve to the purpose of the experiment.

Procedure. The experimental stimuli were presented using a Dell microcomputer, with a monitor running at 85 Hz. The E-Prime software package (Schneider, W., Eschman, A., & Zuccolotto, A., 2002) was used to program the experiment and to collect data. Participants sat at a comfortable distance from the monitor in a room with normal illumination. Text was presented in 18-point font in black against a light gray background.

The stimuli were presented using a variant of the rapid serial visual presentation (RSVP) procedure (Forster, 1970; for discussion see Just, Carpenter, & Wooley, 1982; Potter, 1984). This mode of presentation differed from Wright and Garrett's presentation in which the words appeared cumulatively from left to right. In informal pilot work the two variants of the task were compared, and informants unanimously agreed that the RSVP version rendered the task significantly more natural. All experimental participants reported that they had no difficulty reading or understanding the sentences.

Before each trial, the participant signaled his or her readiness by pressing the spacebar. A fixation cross then appeared on the screen for one second. A sentence was then presented one word at a time in the center of the screen. With the exception of lexical decision targets, each word was displayed for 188 ms before being replaced by the next word. The arrival of a lexical decision target was signaled by a 100 ms tone that began with the offset of the preceding word. This tone was followed by a delay of 206 ms, for a total delay of 306 ms between the end of the preceding word and the onset of the lexical decision target. Lexical decision targets were presented in uppercase lettering and remained on the screen until the participant made a response. On 24 trials randomly intermixed into the experiment, a lexical decision target never appeared. On these trials the sentence ran to its completion, after which a yes-no comprehension question was displayed. Participants used computer keyboard buttons to respond "yes" or "no" (with the left and right hands, respectively) to both the lexical decision targets and post-sentence comprehension questions. Participants received visual feedback of "correct" or "incorrect" after both lexical decision responses and responses to the comprehension questions.

Before beginning the experiment, participants received detailed instructions informing them about the two types of responses they would be required to make (lexical decision and question-answer). These instructions emphasized that both speed and accuracy were important in the lexical decision task, but that speed was of less importance in the comprehension task. Participants then completed a practice block of 14 trials that included both types of stimuli, followed by an opportunity to ask questions of the experimenter. They then completed the experiment without supervision. The entire experimental session typically lasted about 25 minutes.

Materials. Two lists were created from the sentence pairs described above. Each participant saw one version of each item, and 15 or 16 of each type overall. The 31 experimental items were randomly intermixed with the 24 items with comprehension questions and 52 other filler items, for a total of 107 items. The fillers included 27 items in which the target was a pronounceable nonword. On 15 of these trials, this nonword was preceded by a fragment similar to the context fragment used for the experimental items, in which the last two words were a verb and the complementizer *that* (e.g., *The groundskeeper claimed that the GLIPTER*). Including fillers, the length of the pre-target fragment for the lexical decision items ranged from two to eleven words. The items were presented to each participant in an individually randomized order.

Results

Three participants were excluded from the analysis. One was not a native speaker of English; one had median RTs that were approximately 335 ms in each condition, and approximately one-third of his responses fell below a pre-determined cutoff of 300 ms; and one reported after the experiment that he had been diagnosed as having a reading disability. These three participants were replaced.

The participants' mean accuracy on the comprehension questions was .94, with $SD = .07$, and their mean lexical decision accuracy for the experimental items was .98, with $SD = .04$. Accuracy did not differ significantly between experimental conditions, and only correct responses were included in the statistical analyses. Extreme response time outliers were eliminated by trimming response times at 300 ms and 2000 ms, which eliminated less than 1% of responses.

Analyses of variance (ANOVAs) were conducted on lexical decision latency, by participants (F_1) and items (F_2), with target type (adjective or noun) as a within-participants or within-items factor. In this and all subsequent analyses, counterbalancing group (Pollatsek & Well, 1995) was treated as a between-participants or between-items factor, except where noted.

Condition means for Experiment 1 (as well as Experiments 2 and 3) are displayed in Table 1. Lexical decision latency was longer to adjective targets (602 ms) than to noun targets (575 ms), and this difference was significant by both participants and items: $F_1(1, 30) = 11.26, p < .01$; $F_2(1, 29) = 4.93$, p < .05.

Experiment 2

Method

Participants. The participants were 32 members of the University of Massachusetts community, all of whom received either course credit or $5 for their time. All participants had normal or corrected-to-normal vision and were native speakers of American English. All participants were naïve to the purpose of the experiment.

Procedure. The procedure was identical to Experiment 1.

Materials. In two of the experimental conditions the pre-target fragment consisted of the sentence fragment from Experiment 1, including the adjective or noun target from that experiment. The target word in Experiment 2 was a noun that was a plausible continuation in both conditions, e.g.:

(10a) The supervisor decided that the fancy FURNITURE

(10b) The supervisor decided that the porch FURNITURE

In a third condition, the target was preceded by the same fragment without either of the target words from Experiment 1, e.g.:

(10c) The supervisor decided that the FURNITURE

To investigate the question of whether a target noun presented without a preceding sentence fragment would elicit lexical decision response times more similar to those of a predictable or an unpredictable target noun, a final condition was included in which the target was preceded by the names of the cardinal numbers, beginning with the number one, up through the number of words in the context fragment in the (c) condition, e.g.:

(10d) one two three four five FURNITURE

This condition was designed to provide a measure of lexical decision RT for the target nouns in the absence of any preceding sentence context at all, but while approximating other features of the sentence-context conditions, such as uncertainty about the point at which the target would be presented. We refer to (a-d) as the *adjective noun*, *noun noun*, *determiner noun*, and *number noun* conditions, respectively.

Four lists were created from the 31 sets of materials, with each list containing eight items in three of the experimental conditions, and seven items in the fourth condition. Each set of materials appeared once in each of the four conditions. Each list was seen by eight participants. These 31 items were presented along with the 32 experimental items from Experiment 4 (described in Chapter 3), 24 comprehension questions, and 40 other filler items, for a total of 123 items. The fillers included ten lexical decision items with context fragments similar in structure to the ones used in this experiment, but with nonword targets (e.g., *Alex believed that the happy ACERBO; Randy suggested that the window YARM*), and five items like those in the number-noun condition, but with nonword targets (e.g., *one two three four VIRNESS*). Including fillers, the length of the pre-target fragment for the lexical decision items ranged from two to thirteen words.

<u>Results</u>

Of the 32 participants, one was excluded due to accuracy on comprehension questions below a pre-established criterion of 75%. An additional participant was excluded due to accuracy on lexical decision items below a pre-established criterion of 90%. Finally, two participants were excluded due to mean RTs on lexical decision items above a pre-established criterion of 950 ms. These four participants were replaced.

Mean accuracy on the comprehension questions associated with filler items was .92, with SD = .06, and mean accuracy for the lexical decision items in Experiment 2 was .99, with SD = .02. There were no significant differences in accuracy between experimental conditions, and only correct responses were included in the analyses. As in Experiment 1, outliers were eliminated by trimming response times at 300 ms and 2000 ms, which eliminated less than 1% of responses.

The primary predictions for this experiment were of faster lexical decision times in the adjective-noun and determiner-noun conditions than in the noun-noun condition, since only in the latter case is a noun not a predictable continuation of the sentence. The adjective-noun and determiner-noun conditions were not expected to differ, since the presence of an adjective after a determiner does not affect the predictability of a head noun. There was no specific prediction regarding how the number-noun condition would pattern with respect to the other conditions. To test these predictions, one-way ANOVAs were computed with participants (F_1) and items (F_2) as random effects factors. These were followed up with planned comparisons of the condition means.

The one-way ANOVAs revealed significant differences between conditions: $F_1(3, 84) = 4.73, p < .01$; $F_2(3, 81) = 4.25, p < .01$. Comparisons of the condition means (shown in Table 1) revealed that response time in the noun-noun condition (657 ms) was slower than in the adjective-noun (597 ms), determiner-noun (607 ms) , and number-noun (615 ms) conditions (adjective-noun vs. noun-noun, $F_1(1, 28) = 13.36, p < .01$; $F_2(1, 27) = 12.87, p < .01$; determiner-noun vs. noun-noun, $F_1(1, 28) = 13.51, p < .01$; $F_2(1, 27) = 4.62, p < .05$; number-noun vs. noun-noun, $F_1(1, 28) = 4.01, p = .055$; $F_2(1, 27) = 8.37, p < .01$. The adjective-noun, determiner-noun, and number-noun conditions did not differ significantly from each other (all *p*s > .2, with the exception of adjective-noun vs. number-noun, by items, $p > .1$). It is worth noting that the mean in the number-noun condition was highly influenced by a single participant whose mean response time in this condition was 377 ms slower than her average for the other conditions. If this participant is excluded from the analysis, the overall mean response time in the number-noun condition falls between the means of the adjective-noun and determiner-noun conditions.

Experiment 3

Method

Participants. The participants were thirty-six members of the University of Massachusetts community, who were given course credit or paid $5 to participate. All participants had normal or corrected-to-normal vision and were native speakers of American English. All participants were naïve to the purpose of the experiment.

Materials. The materials for this experiment were the 31 sentence pairs like (9a-b) above. As noted, the adjective-noun and noun-noun versions of these sentences were both rated as high in plausibility in a norming study, and did not differ significantly. Also as noted above, the adjectives and nouns that varied between conditions were equated for length and predictability in context (which was essentially zero), and did not differ significantly in frequency or in lexical decision latency in isolation. As in Experiment 2, we refer to the two conditions as the adjective-noun and noun-noun conditions.

Two lists were created from the 31 experimental sentences, with each list containing 15 items in one condition and 16 in the other. Each list was presented to 18 participants. The experimental sentences were intermixed with the 32 sentences from Experiment 5 (described in Chapter 3), as well as 79 other filler sentences. The full set of sentences were presented in an individually randomized order to each participant.

Procedure. Participants were tested individually. Eye movements were recorded using a Fourward Technologies Dual Purkinje Generation 6 eyetracker, which has an angular resolution of less than 10 min of arc. The eyetracker was interfaced with an IBM compatible computer. All sentences in this experiment were displayed on a single line, with a maximum length of 80 characters. While viewing was binocular, only the right eye was monitored. Stimuli were displayed on a 15-inch NEC MultiSync 4FG monitor. Participants were seated 61cm from the computer screen; at this distance, 3.8 characters subtended 1° of visual angle.

On arrival at the laboratory, participants were given instructions and had a bite bar prepared for them that served to stabilize the head. A calibration routine was performed, and its accuracy was checked after each sentence. Participants were instructed to read the sentences for understanding, and to read at a normal rate. After reading each sentence, the participants pressed a button to remove the sentence. The first eight trials of the experimental session were practice trials. Comprehension was checked on approximately 30% of all trials during the experiment by presenting the participant with a yes/no question. Average accuracy for the comprehension questions was above 85%, with no participant scoring below 75%. The entire experiment lasted approximately 30 minutes.

Results

Three regions in each sentence were analyzed. The first two were single-word regions, consisting, respectively, of the word that varied between conditions (e.g., *fancy* and *porch* in 9a and 9b, respectively) and the subsequent head noun (*furniture*), referred to below as the *modifier* region and the *head noun* region. A spillover region that included the next two words of the sentence (*would no*) was also analyzed.

Three reading time measures were computed: *first fixation duration, first pass time* (which is referred to as *gaze duration* when discussing single-word regions), and *go-past time*. First fixation duration is simply the duration of the first fixation in a region, whether it is the only fixation in the region or the first of multiple fixations. First pass time or gaze duration is the sum of all fixations in a region prior to leaving the region for the first time, either to the left or the right. Go-past time (which is also sometimes called *regression path duration*) is the elapsed time from first fixating the region until the reader leaves the region to the right, including any time spent to the left of the region after a regressive eye movement and any time spent re-reading material in the region before moving on. These measures are usually taken to reflect successively later aspects of lexical processing (Rayner, 1998). The first fixation on a word is often affected by factors related to lexical access, such as a word's length, frequency, and predictability in context (e.g., Rayner, Ashby, Pollatsek, & Reichle, 2004). At the other extreme, because go-past time includes time spent outside the region after engaging in a regressive eye movement, it is often affected by higher-level syntactic, semantic, or pragmatic factors (see Clifton, Staub, & Rayner, in press, for a review).

Prior to all analyses, sentences with track losses were excluded (less than 2% of trials). In addition, fixations less than 80 ms in duration, and within one character of the previous or subsequent fixation, were incorporated into this neighboring fixation. The same procedure was used to incorporate fixations less than 40 ms in duration and within three characters of the previous or subsequent fixation. Remaining fixations of less than 80ms were deleted, as were fixations of longer than 800 ms. It is thought that readers do not extract useful information from fixations shorter than 80 ms (see Rayner & Pollatsek, 1989), and that fixations longer than about 800 ms are likely to reflect track losses. Less than 2% of all fixations were eliminated.

To test the predictions of longer reading times on the modifier in the adjective-noun condition and longer reading times on the head noun in the noun-noun condition, comparisons of the participant (F_1) and item (F_2) means in each of the two regions were computed. Though there were no specific predictions regarding the spillover region, the same comparisons of means were performed for this region. Condition means are presented in Table 1.

Modifier region. On the modifier region, the first fixation duration was longer in the adjective-noun condition than in the noun-noun condition (248 ms vs. 242 ms). This difference was marginally significant: $F_1(1, 34) = 3.60$, $p = .07$, $F_2(1, 29) = 3.00$, $p = .09$. Gaze duration was also longer in the adjective-noun condition (280 ms vs. 264 ms), and this difference was fully significant: $F_1(1, 34) = 5.07$, $p < .05$; $F_2(1, 29) = 5.40$, $p < .05$. Finally, go-past time was also longer in the adjective-noun condition (308 ms vs. 278 ms), and again, this difference was significant: $F_1(1, 34) = 8.53$, $p < .01$; $F_2(1, 29) = 9.71$, $p < .01$.

Head Noun region. First fixation duration was longer on the head noun in the noun-noun condition than in the adjective-noun condition (279 ms vs. 275 ms), as was gaze duration (306 ms vs. 300 ms). However, neither of these differences approached significance (*p*s > .3). There was essentially no difference between conditions on the go-past measure (329 ms in both conditions).

Spillover region. On the spillover region, reading times on all three measures were numerically longer in the noun-noun condition than in the adjective-noun condition. These differences did not approach significance on the first fixation duration or gaze duration measures (*p*s > .4), and the difference in go-past time (431 ms vs. 408 ms) was marginally significant: $F_1(1, 34) = 3.49, p = .07$; $F_2(1, 29) = 3.61$, $p = .07$.

Post hoc analyses revealed that combining across the modifier and head noun regions, there were no significant effects of condition; in other words, there were no significant differences in reading time between the two-word adjective-noun and noun-noun sequences. The differences in opposite directions on the modifier and head noun regions resulted in a significant interaction of condition and region on the gaze duration measure: $F_1(1, 34) = 4.56, p < .05$; $F_2(1, 29) = 7.60, p = .01$.

Discussion of Experiments 1-3

The pattern of results for these three experiments is easily summarized. Experiment 1 demonstrated that lexical decision RT is longer on an adjective than a noun following a determiner, i.e., in a syntactic environment in which a noun, but not an adjective, is a predictable phrasal head. This effect was not plausibly generated by differences in the lexical characteristics of the adjectives and nouns, since these words were matched on length and lexical predictability (which was essentially zero), and did not differ significantly in frequency. Experiment 2 demonstrated that lexical decision RT is longer for a head noun following a nominal modifier (i.e., when a noun is not a predictable phrasal head) than following an adjective. The two additional conditions in Experiment 2, the determiner-noun and number-noun conditions, both behaved very similarly to the adjective-noun condition. The finding that the determiner-noun condition did not differ from the adjective-noun condition, but was significantly faster than the noun-noun condition, offers further support to the hypothesis that it the predictability of the target as a phrasal head that is responsible for the difference between the adjective-noun and noun-noun conditions. The finding that the number-noun condition was also significantly faster than the noun-noun condition, and not significantly different from the other conditions, suggests that, at least to the extent that the number-noun condition can be regarded as a neutral baseline, the effect of interest is inhibitory rather than facilitatory. That is, lexical decision RT was slowed compared to the number-noun baseline when the target word was not a predictable phrasal head, but was not speeded compared to this baseline when the target word was a predictable phrasal head. As noted in the Introduction, this pattern is to be expected if syntactic context effects operate at a post-lexical-access stage.

In Experiment 3, reading time was longer on an adjective than a noun following a determiner; this effect first appeared in the reader's first fixation on the word, and reached full significance in the gaze duration and go-past measures. However, the RT difference on the head noun between the adjective-noun and noun-noun conditions that was observed in Experiment 2 did not appear in the reading time measures in Experiment 3; first fixation duration and gaze duration were numerically longer on the head noun when it followed a noun than when it followed an adjective, but this difference did not approach statistical significance.

There is a straightforward explanation for the failure to replicate the lexical decision effect on the head noun in the eyetracking paradigm. This explanation emphasizes the role of spillover effects. A frequently replicated finding in the eye movement literature is that increasing the difficulty of lexical processing on word *n* increases reading time on word *n*+1. Rayner and Duffy (1986), for example, manipulated the frequency of a target word, resulting in gaze durations of 330 ms and 243 ms for low- and high-frequency words, respectively. Though the rest of the sentence was identical in the two conditions, they found that gaze duration on the next fixated word was 296 ms when the target word was low frequency, and 259 ms when the target word was high frequency, a significant difference. In other words, an 87 ms difference in gaze duration on the target word translated into a 37 ms difference, in the same direction, on the next fixated word. Similarly, Rayner, Sereno, Morris, Schmauder, and Clifton (1989) manipulated the frequency of a prenominal adjective (e.g., *acoustic guitar* vs. *electric guitar*), and found a gaze duration difference of 73 ms on the adjective, and 29 ms on the subsequent noun. (This latter result was fully significant only in the items analysis, due to relatively low power in the participants analysis, with only 12 participants.) These two experiments not only demonstrate the existence of spillover effects, but also give a remarkably consistent estimate of their size: the difference in gaze duration on word *n*+1 caused by spillover processing from word *n* was 40-42% of the gaze duration difference on word *n*. Other studies, however, have reported even larger spillover effects. For example, Rayner, Warren, Juhasz, & Liversedge (2004) compared the effects of two different types of semantic anomaly on reading times, and found a 17 ms gaze duration effect on the critical word, but a 26 ms first pass effect in the same direction on the subsequent two-word region, which was the same across conditions. In other words, the spillover effect was larger than the effect on the critical word itself. The same pattern was reported by

Schroyens, Vitu, Brysbaert, and d'Ydewalle (1999) in an experiment manipulating word frequency.

Two different types of underlying processes may combine to account for the presence of spillover effects. Within the framework of the E-Z Reader model of eye movement control in reading (Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Rayner, & Pollatsek, 2003), spillover effects arise when the difficulty of processing word *n* reduces the resources that the reader can devote to parafoveal processing of word *n*+1 before directly fixating this word. Support for this idea comes from experiments demonstrating that increased foveal processing difficulty reduces the amount of benefit readers obtain from having a valid parafoveal preview of the next word (e.g., Henderson & Ferreira, 1990; Schroyens et al., 1999). On the other hand, it is also possible that when word *n* is difficult to process (either at the level of lexical access or because of difficulty with semantic or syntactic integration), the reader is still engaged in some aspect of the processing of word *n* when the eyes are fixated on word *n*+1, leading to increased fixation times on that word. This latter account provides the most plausible explanation of the Rayner et al. (2004) data described above, and is supported by numerous studies of syntactic processing that have found effects of processing difficulty that appear only after the eyes have left the difficulty-inducing word (see Clifton et al., in press, for a review).

In the current experiment, the differential processing difficulty on the modifier region may have made it essentially impossible for the predicted effect to appear on the head noun. An adjective in modifier position was significantly more difficult to process than a noun, and it is likely that in the absence of any difference in the processing demands on the next word, this next word would have taken longer to read following the adjective than following the noun. A post hoc analysis provides additional support for this conclusion. This analysis examined the correlation between two difference scores, by items: the difference in gaze duration on the modifier between the adjective-noun and noun-noun conditions, and the difference in gaze duration on the head noun between the adjective-noun and noun-noun conditions. This correlation was $r = .40$, $p = .02$, indicating that reading time on the head noun was indeed affected by the difficulty of processing the preceding modifier. The harder the adjective was to process, compared to the corresponding noun, the longer readers spent on the subsequent head noun in the adjective-noun condition compared to the noun-noun condition.

Using a relatively conservative estimate of the size of the spillover effect based on the Rayner and Duffy (1986) and Rayner et al. (1989) studies, a correction was performed to provide an estimate of the gaze duration effect on the head noun in the absence of spillover effects. First, the size of the spillover effect was estimated for each subject and for each item, at 40% of the difference in gaze durations between the adjective and noun in modifier position. This estimated spillover effect was then subtracted from the gaze duration on the head noun in the adjective-noun condition. Following this correction, the mean gaze duration effect on the head noun was 13 ms (306 ms in the noun-noun condition vs. 293 ms in the adjective-noun condition), which was marginally significant: $F_1(1, 34) = 2.67$, $p = .11$; $F_2(1, 29) = 3.71$, $p = .06$. Obviously, a less conservative estimate of the size of the spillover effect from the modifier region would have resulted in this difference reaching full significance.

In sum, it appears that the failure to replicate the result of Experiment 2 in the eyetracking paradigm has a straightforward explanation in terms of the dynamics of eye movements, and should not be regarded as evidence against the hypothesis under consideration, i.e., that lexical processing is affected by a word's status a predictable phrasal head. When the effect of spillover processing is estimated and removed, there is a strong suggestion of an effect on the head noun, with longer reading times in the noun-noun condition than in the adjective-noun condition. Obviously, this result is merely suggestive, given the speculative nature of the correction that was performed. Note, however, that it is quite clear why such spillover effects did not appear on the head noun in the lexical decision paradigm used in Experiment 2. In that paradigm, no parafoveal processing is possible in any case, and almost 500 ms elapsed between the onset of the last word of the context fragment and the onset of the target itself. This is likely to be long enough for participants to complete both lexical and syntactic processing of the context fragment before the onset of the target word.

The finding that a noun was processed faster than an adjective following a determiner, in Experiment 3, may be the first clear demonstration that syntactic category has an effect on eye movements in the absence of syntactic misanalysis. It is well known that readers experience processing difficulty very soon after encountering a word whose category disconfirms the reader's initial syntactic analysis (a phenomenon first demonstrated by Frazier & Rayner, 1982, and since reported by many others). The present experiment, on the other hand, shows a difference in reading times based on syntactic category in a context in which either of the categories could be legally attached into the phrase marker. The critical difference between the conditions was merely that in one case the word's syntactic category was a predictable phrasal head, while in the other it was not.

The finding of a difference in reading times between adjectives and nouns also sheds light on a result obtained by Frazier and Rayner (1987). In three eyetracking experiments examining the resolution of syntactic category ambiguities, Frazier and Rayner found, among other things, that a noun such as *desert* was read more quickly when the preceding context left it ambiguous whether it was a head noun or a modifier (e.g., *I know that the desert…*) than when it could only be a modifier, since the head noun analysis was ruled out by an agreement conflict (e.g., *I know that these desert…*). The authors interpreted this result as reflecting the difficulty of accessing a modificational use of the critical noun. However, the present experiment found that unambiguous adjectives were also read slowly after a determiner, compared to nouns. Therefore, it is possible that the effect reported by Frazier and Rayner is not in fact due to difficulty associated with interpreting a noun as a modifier, but instead due to general difficulty with a modifier in this position, compared to a head noun.

CHAPTER 3

EXPERIMENTS 4-5

Overview of the Experiments

As noted in Chapter 1, Wright and Garrett (1984) found a lexical decision advantage for adjective targets when an adjective was a predictable phrasal head, compared to when an adjective was a legal continuation of the preceding fragment but not a predictable one. Experiments 4 and 5 attempted to replicate this result in the lexical decision and eyetracking paradigms, respectively. As in Wright and Garrett's experiment, the adjective's status as a predictable phrasal head was manipulated by including or omitting a degree adverb as the last word of the preceding context.

Experiment 4 was run in the same experimental session as Experiment 2. The experiment employed a 2 x 2 design that crossed target type with context type. The target was either a common English adjective (e.g., *visible*) or a pronounceable nonword matched with the adjective in length (e.g., *revibel*). The context fragment ended with the word *the*, or with the word *the* followed by a degree adverb (e.g., *highly*). The basic prediction was that lexical decision RT would be faster for adjectives, but not nonwords, when the context ended in a degree adverb. The nonword conditions were included as controls in this experiment, but not in the previous lexical decision experiments, because it was possible that the degree adverb would have a general facilitatory effect merely by virtue of adding an extra word to the fragment that preceded the target. Including the nonword condition would help to rule out this artifactual explanation. In Experiment 1 the context fragment was identical in the two conditions, and in Experiment 2 the context fragment was matched in length in the adjective-noun and noun-noun conditions, and matched in the determiner-noun and number-noun conditions, eliminating the need for the nonword control.

Experiment 5 was run as part of the same session as Experiment 3. The critical adjectives were embedded in full sentences, and as in Experiment 4, the adjective was either preceded by a determiner or by a determiner followed by a degree adverb. The presence of a degree adverb was expected to reduce reading times on the adjective. In light of previous demonstrations of spillover processing from a modifier onto the subsequent noun (see Rayner et al., 1989, and Chapter 2 above), it seemed likely that some effect of the degree adverb might also appear on the noun following the adjective.

Experiment 4

Method

Participants and Procedure. Experiments 2 and 4 were conducted with the same 32 participants, with the materials intermixed in a single experimental session.

Materials. Thirty-two common adjectives were used as target words. Pronounceable nonwords were selected that matched these adjectives in length. Sixteen of the word/nonword pairs were those used by Wright and Garrett (1984, Exp. 4). Sixteen additional pairs were created to supplement these.

Each word or nonword target was preceded by a sentence fragment. Sixteen of these fragments were modified versions of fragments used by Wright and Garrett (1984, Exp. 4). These were supplemented with sixteen new fragments. All 32 fragments ended with a verb, followed by the word *the*, then, in two of the four conditions, a degree adverb. A sample set of materials is shown below.

(11a) The ducks in the campus pond tend to eat the totally SLIMY

(11b) The ducks in the campus pond tend to eat the totally SPINT

(11c) The ducks in the campus pond tend to eat the SLIMY

(11d) The ducks in the campus pond tend to eat the SPINT

We refer to (a-d) as the *adverb adjective* condition, the *adverb nonword* condition, the *no adverb adjective* condition, and the *no adverb nonword* condition, respectively. The full set of materials is presented in Appendix B.

These materials were designed so that the specific adjective that served as the target was not predictable on the basis of the context fragment. Note, however, that this issue is of limited relevance for the present experiment due to the fact that the only difference between conditions is in the presence or absence of a degree adverb. Logically, the predictability of any specific adjective must be somewhat higher when the preceding fragment ends with a degree adverb, since this limits the possible continuations to adjectives and possibly adverbs. However, the *relative* predictability of any specific adjective, compared to other adjectives, is unlikely to differ much, if at all, between conditions.[3]

Four lists were created from the 32 sets of materials, with each list containing eight items in each of the four experimental conditions. Each set of materials appeared once in each of the four conditions. Each list was seen by eight participants.

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[3] The degree adverb does restrict the possible continuations to "gradeable" adjectives; e.g., except in ironic or metaphorical contexts, *very* cannot be followed by *mammalian* or *dead*. Since the set of gradeable adjectives is so large, this restriction is still not likely to make a meaningful difference in the predictability of any specific adjective.

The 32 experimental items were randomly intermixed with a total of 91 other sentences, including the materials for Experiment 2, as described above.

Results

Participants' mean accuracy for the lexical decision items in Experiment 3 was .98, with *SD* = .03. There were no significant differences in accuracy between experimental conditions, and only correct responses were included in the analyses. As in Experiments 1 and 2, outliers were eliminated by trimming response times at 300 and 2000 ms, which again eliminated less than 1% of responses.

Analyses of variance were conducted with participants and items as random effects factors, and with target type (adverb or nonword) and the presence or absence of a degree adverb as within-participants or within-items factors.[4] The ANOVAs revealed a main effect of target type, with faster RT for words than for nonwords, $F_1(1, 28) = 4.51, p < .05$; $F_2(1, 31) = 5.79, p < .05$. There was a significant interaction of target type with context type, $F_1(1, 28) = 7.53, p < .02$; $F_2(1, 31) = 4.04, p = .05$. The main effect of context type did not approach significance (*p*s > .2). Condition means are presented in Table 2.

Response times were significantly faster to adjective targets when the degree adverb was present (635 ms) than when it was absent (665 ms): $F_1(1, 28) = 4.33, p < .05$; $F_2(1, 31) = 5.76, p < .05$. Response times to nonwords were slower when they followed an adverb (690 ms vs. 678 ms), but this difference did not approach significance (*p*s > .2).

[4] In the analyses for this experiment, counterbalancing group was included as a between-participants factor, while the items analysis used a pooled error term. In the items analysis counterbalancing group accounted for a negligible portion of variance, but the resulting loss of 3 *df* reduced one otherwise significant effect to marginal significance.

Experiment 5

Method

Participants and Procedure. Experiments 3 and 5 were run as part of the same experimental session, with the same participants and identical procedures. Due to a programming error, four participants' data (two in each counterbalancing condition) had to be excluded from Experiment 5, so that there were 32 rather than 36 participants in this experiment.

Materials. The materials for this experiment included 32 sentence pairs like (12a-b) below:

(12a) The auto mechanic used some flexible plastic to fix the problem.

(12b) The mechanic used some very flexible plastic to fix the problem.

The critical difference between the two versions was the presence or absence of a degree adverb before the adjective that modified the direct object of the main verb. The same adjective-noun sequences were used in this experiment as in Experiment 4. The (a) and (b) conditions will be referred to as the *no adverb* and *adverb* conditions, respectively. In this experiment four degree adverbs were used: *very*, *fairly*, *totally*, and *slightly*, with each degree adverb appearing in eight of the 32 items. In order to minimize effects of the length of the preceding word on landing position on the adjective, the determiner was always matched with the degree adverb in length, so that the word that preceded the adjective was the same length between conditions. To make this length-matching possible, it was necessary to make use of determiners of various types, including numbers (e.g., *eleven*), quantifiers (e.g., *several*), and possessive NPs (e.g., *Pete's*).

A second difference between conditions was that in the no adverb version, a modifier that was the same length as the degree adverb was inserted early in the sentence. This word was added so that the critical adjective would appear in exactly the same linear position in the two versions of each sentence. The full set of materials is presented in Appendix C.

Two lists were created from the 32 experimental sentences, with each list containing 16 items in each condition. Each degree adverb appeared four times on each list, and each list was presented to 16 participants. As noted above, these sentences were intermixed with the 31 experimental sentences from Experiment 3 and 79 other filler sentences, and the full set of sentences was presented in an individually randomized order to each participant.

Results

Three regions were analyzed in each sentence. These were simply the critical adjective (*flexible*), the following noun (*plastic*), and a spillover region that consisted of the remainder of the sentence. The three reading time measures that were computed in Experiment 3 were also computed for this experiment: first fixation duration, first pass time/gaze duration, and go-past time. Less than 2% of trials were eliminated due to track losses, and less than 2% of all remaining fixations were eliminated due to falling outside the 80-800 ms range. Condition means are presented in Table 2.

On the adjective, there was no effect of the degree adverb on first fixation duration, with essentially identical times in the no adverb and adverb conditions (274 ms vs. 275 ms). Gaze duration was longer in the no adverb condition (315 ms vs. 306 ms), as was go-past time (366 ms vs. 349 ms). These differences were in the predicted direction, but they did not reach significance (*ps* > .15).

The first fixation on the noun was longer in the no adverb condition than in the adverb condition (277 ms vs. 267 ms). This difference was significant by participants, but not by items: $F_1(1, 30) = 4.99, p < .05$; $F_2(1, 30) = 2.80, p = .11$. Gaze duration was also longer in the no adverb condition (316 ms vs. 293 ms), and this difference was fully significant by both participants and items: $F_1(1, 30) = 30.49, p < .01$; $F_2(1, 30) = 6.93, p < .02$. Finally, there was a go-past difference in the same direction (351 ms vs. 328 ms), which was significant by participants, but not by items: $F_1(1, 30) = 4.38, p < .05$; $F_2(1, 30) = 2.75, p = .11$.

On the spillover region, there was no sign of a significant difference between conditions on the first fixation measure (*ps* > .5). First pass reading time was longer in the adverb condition (634 ms vs. 602 ms): $F_1(1, 30) = 8.91, p < .01$; $F_2(1, 30) = 5.92, p < .05$, but given that there was no hint of such a difference in go-past time (704 ms in both conditions), we do not attempt to offer a theoretical explanation of this finding.

<u>Discussion of Experiments 4 - 5</u>

The results of Experiment 4 replicated Wright and Garrett's (1984) finding that lexical decision RT on an adjective is faster when the adjective is preceded by a degree adverb than when the adjective follows a determiner directly. The presence of a degree adverb did not speed RT for nonwords; in fact, RT was numerically longer for the nonwords when the degree adverb was present than when it was absent.

These results suggest, once again, that the syntactic category predictability effect in the lexical decision task is due to inhibition when the target word is not predictable, rather than to facilitation when the target is a predictable phrasal head. When the adverb was present, RT was 55 ms shorter to adjective targets than to nonword targets, a difference that was highly significant (*p*s < .01). But when the adverb was absent, the difference between the adjective and nonword conditions was only 13 ms, which did not approach significance (*p*s > .2). In other words, the robust advantage for words over nonwords in the lexical decision task (e.g., Grainger & Jacobs, 1996) was present in the adverb conditions, but essentially disappeared when the adverb was absent. The absence of an advantage for words over nonwords in the no adverb condition suggests a slowing of "yes" responses in this condition.

In Experiment 5, gaze duration and go-past time were numerically shorter on the adjective when this word was preceded by a degree adverb, but this difference did not reach significance. On the noun following the adjective, the presence of the degree adverb resulted in faster reading times on all three measures, with this difference reaching full significance in gaze duration. The failure to find a significant effect on the adjective is obviously in need of explanation. Furthermore, in light of the nonsignificant result on the adjective, the finding of a significant effect on the subsequent noun, which was the same word in both conditions and was two words removed from the degree adverb, is also quite surprising on its surface. These two issues are addressed in the remainder of this section.

The results on the adjective can naturally be explained, once again, by examining the role of spillover processing. If the degree adverb were difficult to process compared to the determiner in the no adverb condition, this would have resulted in differential spillover processing on the adjective. As was the case with the head noun in Experiment 3, this effect would have counteracted, at least in part, the effect of syntactic category predictability on the adjective. In fact, there is clear evidence that the degree adverb was relatively difficult to process compared to the determiner that preceded the adjective in the no adverb condition. Gaze duration was longer on this adverb (300 ms) than on the corresponding determiner (287 ms), and this difference was nearly significant by items: $F_1(1, 30) = 2.50, p = .13$; $F_2(1, 30) = 3.80, p = .06$. (Note that, as would be expected, reading times on the determiner itself were very similar across the two conditions; gaze duration was 287 ms in the no adverb condition and 285 ms in the adverb condition.) The duration of the last fixation before fixating the adjective was significantly longer when an adverb preceded the adjective than when a determiner preceded the adjective (273 ms vs. 259 ms): $F_1(1, 30) = 4.90, p < .05$; $F_2(1, 30) = 10.65, p < .01$.

Interestingly, there is a natural explanation in terms of syntactic category predictability of longer reading times on the degree adverb than on the determiner. When the reader of (6a-b) encounters the verb *used*, the fact that this verb has a strong transitive bias (indeed, in the example sentence the verb may be obligatorily transitive) would enable a parser with a top-down component to predict the arrival of a direct object noun phrase, and to predict a specifier within this phrase. The determiner *some* is therefore a predictable syntactic constituent.[5] On the other hand, the degree adverb *very* is not a predictable constituent.

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[5] On the DP hypothesis of Abney (1987), this determiner is the head of the phrase *some flexible plastic*, so we may regard the determiner as a predictable phrasal head.

The same post hoc correction that was used in interpreting the results of Experiment 3 can also be used in the present case to assess the effect of differential processing difficulty on the word prior to the adjective. This correction consists of reducing gaze durations on the adjective, in the adverb condition, by an increment corresponding to 40% of the gaze duration difference on the previous word. The resulting gaze duration difference on the adjective is 14 ms (315 ms in the no adverb condition vs. 301 ms in the adverb condition): F_1 (1, 30) = 2.97, p = .10; F_1 (1, 30) = 2.59, p = .12. Again, a less conservative estimate of the spillover effect would have resulted in this effect reaching significance.

As noted above, spillover effects would not be expected in the lexical decision paradigm used in Experiments 1, 2, and 4, since there is no possibility for parafoveal preview, and in addition almost 500 ms elapsed between the onset of the last word of the context fragment and the onset of the target word. As a result, the facilitatory effect of the degree adverb was able to appear on the adjective in Experiment 4. Comparing the results of Experiments 2 and 4 to the results of Experiments 3 and 5, it appears that the word-by-word presentation used in the lexical decision paradigm affects where the syntactic category predictability effect appears. However, there is clear evidence that the effect itself does appear both in the lexical decision task and in normal reading.

What remains to be explained in the results of Experiment 5 is the benefit from the degree adverb on the noun that appeared two words downstream. The most straightforward explanation is that the degree adverb enabled readers to shift attention at an earlier point from processing the adjective to processing the subsequent noun.

Within the framework of the E-Z Reader model, for example, it is possible that when the adverb was present readers obtained more complete parafoveal preview of the noun while still fixating the adjective, since the relevant aspects of adjective processing may have terminated earlier in this condition.

However, it is also worth considering a very different explanation for the fact that the degree adverb had such a clear facilitatory effect on the noun. Kamp and Partee (1995) have suggested a principle of semantic interpretation called the "Head Primacy Principle." This principle proposes that modifier interpretation depends on the interpretation of the head: the head of, e.g., an NP is interpreted relative to its context, and any modifiers of this head are interpreted relative to "the local context created from the former context by the interpretation of the head" (p. 161). In the case of so-called non-intersective adjectives (e.g., Heim & Kratzer, 1998), it is easy to see why such a principle is necessary: the interpretation of the adjective *large* in expressions like *large mouse* and *large airplane* clearly depends in a crucial way on the noun that it modifies. If this principle is interpreted in processing terms, it implies that the semantic interpretation of a prenominal modifier is delayed, at least in part, until the head noun is interpreted. Indices of processing difficulty on the head noun will therefore measure both the processing difficulty of the noun itself and the difficulty of interpreting the preceding modifier in light of the interpretation of the noun. It is possible, then, that a degree adverb before an adjective-noun sequence speeds processing of the head noun because it prepares the semantic processor for an upcoming modification relationship, the processing of which occurs primarily on the noun. When the degree adverb is present, the semantic processor may be able to complete the work of interpreting the adjective-noun sequence more quickly than it otherwise might.

CHAPTER 4

GENERAL DISCUSSION

In this chapter, I begin by relating the results of the five experiments presented here to the three goals set out in the introduction. These three goals were: a) to replicate Wright and Garrett's (1984) finding that lexical decision RT to adjectives and nouns was affected by the target word's status as a predictable phrasal head, while eliminating potential criticisms of Wright and Garrett's experimental materials; b) to test the prediction, based on these results, of differences in lexical decision RT between adjectives and nouns; and c) to generalize these results to a more natural eyetracking paradigm. I then discuss the theoretical interpretation of the experimental findings, considering both Wright and Garrett's explanation in terms of a predictive parsing strategy and two possible alternate explanations. Finally, I discuss the implications of these results for models of visual word recognition and eye movement control in reading.

Experiments 2 and 4 successfully replicated Wright and Garrett's key findings. In Experiment 2, lexical decision RT was longer to a noun target when the last word of the preceding fragment was a noun than when the last word was an adjective or a determiner. Unlike in Wright and Garrett's materials, the noun-noun compounds that were used were all plausible, natural expressions, as demonstrated by the results of a plausibility norming study. In Experiment 4, RT to an adjective was slower when this adjective was directly preceded by a determiner than when it was preceded by a determiner and a degree adverb. Unlike in Wright and Garrett's materials, the presence or absence of the degree adverb was the only difference between conditions.

The results of Experiments 2 and 4 also suggested that the experimental effects were due to inhibition, not facilitation. In Experiment 2, the number-noun condition, in which the target noun appeared without a sentence context, patterned with the adjective-noun and determiner-noun conditions, while the noun-noun condition was slower. In Experiment 4, the typical advantage for words over nonwords disappeared when the adverb was absent, suggesting a slowing of "yes" responses to adjective targets. These findings reinforce Wright and Garrett's contention that the effect of syntactic context most likely operates at a post-lexical stage.

Experiment 1 compared lexical decision RT to nouns and adjectives following a determiner. In this context, a noun is a predictable phrasal head, but an adjective is not. Though the adjectives and nouns were matched on length and did not differ significantly in frequency, and though none of the specific target words were predictable in context, RT was faster to nouns than to adjectives.

In the eyetracking experiments (Experiments 3 and 5), the pattern of results was more complex. In Experiment 3, nouns were read faster than adjectives following a determiner, replicating the lexical decision results obtained in Experiment 1. However, there were no significant reading time differences on the subsequent noun, failing to replicate the results of Experiment 2. In Experiment 5, the presence of a degree adverb speeded reading of a subsequent adjective-noun sequence, but the effect was significant only on the noun, two words downstream from the degree adverb.

As discussed above in some detail, the pattern of results from the two eyetracking experiments has a natural explanation in terms of spillover effects: in Experiment 3, the differential processing difficulty on the modifier may have worked to counteract the predicted effect on the subsequent noun, while in Experiment 5, the differential processing difficulty on the word before the critical adjective (determiner or degree adverb) may have worked to counteract the predicted effect on the adjective. In the eyetracking literature, there is (to my knowledge) a notable absence of experimental results in which significant differences in reading times, in opposite directions, emerge on two subsequent words. This is precisely what would have had to happen in order to replicate precisely the lexical decision results in the eyetracking experiments.

Taken together, the results of the five experiments presented here are consistent with Wright and Garrett's proposal of a top-down parsing mechanism that predicts obligatory phrasal heads, and of a confirmation procedure that checks for the satisfaction of such predictions. There is evidence that this predictive mechanism and confirmation procedure may operate not only in tasks such as lexical decision that require an overt response, but also in normal reading. However, the present results do not address more specific questions about the nature of the predictive mechanism; essentially, the question of what exactly it means for the parser to issue a syntactic prediction is still unanswered. One possibility is that the parser does, in fact, predictively build whatever structure is required in order to attach obligatory constituents into the phrase marker that has already been built based on the lexical input. If this is right, then the arrival of a word that does not immediately confirm a syntactic prediction (e.g., an adjective after a determiner) would require a form of syntactic reanalysis, as the predictively-built structure is modified so that this word can be attached into the phrase marker. On the other hand, perhaps the parser fully constructs only that part of the predicted structure that is certain, leaving other aspects of the structure unspecified, such as whether a predicted head noun will be preceded by a modifier. Note, however, that there are at least some cases in which it is not necessary to leave any part of the predicted structure unspecified, namely, cases in which it is certain that the predicted constituent will arrive next in the input. This is the case after a degree adverb, which can only be followed by an adjective (or at least, an adjective phrase, e.g., *the very recently arriving soldiers*…). In short, while the present results suggest that the parser does indeed make syntactic predictions, they do not clarify how the notion of "making syntactic predictions" should be thought of in concrete processing terms.

An issue that is orthogonal to the one just discussed is whether the parser's predictions are based on the requirements of the grammar, or whether they are based on transitional probabilities. Wright and Garrett emphasize the former view, but in fact it is rather difficult to tease apart the predictions of the two positions. Constituents that are grammatically obligatory are, by definition, highly frequent sentence continuations. The crucial test would involve determining whether processing is speeded when a word's syntactic category is highly frequent in a given sentence position, but is not grammatically obligatory. We note that Staub, Clifton, and Frazier (in press) recently carried out a version of this test, comparing reading times on the verb's direct object in heavy NP shift constructions when the verb was obligatorily transitive and when it was optionally transitive but strongly transitive-biased. Staub et al. reported significantly shorter reading times on the shifted noun phrase when the verb was obligatorily transitive, suggesting that in this construction, at least, it is possible to tease apart the effect of grammatical obligatoriness from the effect of frequency.

In addition, there are at least two plausible objections to interpreting the results of these five experiments in terms of a syntactic category predictability effect. The first of these is targeted specifically at the interpretation of effects on the head noun in Experiments 2 and 3, while the second is more general and relates to all five experiments.

In Experiments 2 and 3, the condition in which the head noun is not a predictable phrasal head is one in which this noun is the second constituent of a noun-noun compound. It is possible that when a reader (or listener) encounters such a compound, he or she initially analyzes the first noun as the head of the noun phrase, then has to engage in a minor syntactic reanalysis upon encountering the second noun in order to attach the first noun as a modifier. This would seem to be especially likely when the first noun is a plausible head, as it is in (9b), repeated here:

(9b) The supervisor decided that the porch furniture would no longer be produced.

In reading this sentence, the reader may initially take *the porch* to be the subject of the embedded clause. If this is in fact how such noun-noun compounds are processed, then slowed lexical decision RT and reading times on the head noun could be attributed to disruption due to the need for syntactic reanalysis, rather than to the fact that this noun is not a predictable phrasal head.

This objection has some force. To my knowledge, there have been no published studies of the processing of noun-noun compounds that would directly address this question, but given the parser's general preference for rapid incremental interpretation (e.g., Crocker, 1996; Frazier, 1987a; Marslen-Wilson, 1973), it is certainly possible that the first noun is initially attached as the head of the noun phrase. With this in mind, what Wright and Garrett's hypothesis has in its favor is, essentially, parsimony. This hypothesis makes sense of the results of all five experiments, while the alternate hypothesis under consideration can only account for the finding of slowed responses when a noun is the second constituent of a compound; a separate explanation would be required in order to make sense of the adjective results, for example.

The second objection points out that in these experiments a word's status as a predictable phrasal head is confounded with the *amount* of syntactic structure that has to be built in order to attach the word. On standard phrase-structural assumptions, more structure is needed to attach an adjective than a noun after a determiner, and more is needed to attach an adjective after a determiner than after a degree adverb. (Whether more structure must be built to attach a noun after another noun than after a determiner or adjective depends on the details of one's syntactic representation of noun-noun compounds; see, e.g., Selkirk, 1982). Therefore, it is possible that the effects observed here are due not to the predictability of a word's syntactic category, but rather to the fact that the target words in the "unpredictable" conditions simply required more syntactic structure building in order to be attached into the phrase marker.

Again, this is a cogent objection, and in fact it cannot be ruled out entirely. However, it is worth noting that the finding of measurable processing effects based on small amounts of syntactic structure building would be entirely novel. For example, given standard syntactic assumptions, only one additional node is required to attach an adjective, rather than a noun, after a determiner. It may not be plausible to hold the construction of this single node responsible for the significant difference in gaze duration on the modifier in Experiment 3.

Finally, it is appropriate to ask whether the present results have significant implications for models of visual word recognition and of eye movement control in reading. Experiments 2 and 4 provided some indication that the effect of a word's status as a predictable phrasal head is inhibitory, rather than facilitatory: RT was slowed when the target was not a predictable phrasal head, but did not appear to be speeded when the target was a predictable phrasal head. These results are consistent with the conclusion drawn by many previous researchers (see Chapter 1) that effects of syntactic context on lexical processing are not effects on lexical access itself. If RT had been faster in the adjective-noun and determiner-noun conditions of Experiment 2 than in the number-noun condition, this would have suggested an effect on lexical access itself; but there was essentially no indication of this pattern.

With these results in mind, it seems appropriate for models of visual word recognition (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Harm & Seidenberg, 2004) to continue to ignore syntactic context effects. (Whether semantic context effects can be ignored is, obviously, a separate question.) Though these models make competing claims regarding many issues, they are united in their assumption that the only information relevant to the process of visual word recognition, up through the stage of lexical access, is contained within the word itself. The present results do nothing to undermine this assumption.

With respect to models of eye movement control, the situation is different. My remarks directly address the E-Z Reader model (Reichle et al., 1998, 2003), which is arguably the best-known and most influential model, but I intend for them to apply equally to other prominent models such as SWIFT (Engbert, Nuthmann, Richter, & Kliegl, in press). In the E-Z Reader model, the predictability of a word in context, along with word length and frequency, is one of the central variables used to predict fixation times on the word. Numerous experimental studies (e.g., Balota, Pollatsek, & Rayner, 1985; Ehrlich & Rayner, 1981; Rayner et al., 2004; Rayner & Well, 1996) have demonstrated that readers spend less time fixating words that are highly predictable in context (as determined by Cloze probability) than words that are relatively unpredictable in context. But while this factor is usually referred to merely as predictability, what it actually reflects is the predictability of a given word, holding syntactic category constant. In the studies just cited, the high- and low-predictability targets are always of the same syntactic category; in fact, they are always nouns.

It is likely, of course, that words that are ranked high in predictability based on a Cloze procedure will fall within the same syntactic category. For example, in the norming study conducted in advance of Experiments 1-3, the goal of which was to ensure that the adjectives and nouns used in those experiments did not differ in lexical predictability, almost all responses were nouns, despite the fact that an adjective was a perfectly legal continuation. It follows that no adjective is likely to receive a high predictability score in this context. However, low- or zero-predictability words could be either adjectives or nouns. What Experiments 1 and 3 demonstrate quite clearly is that within the space of low-predictability words, syntactic category predictability has a significant effect on both lexical decision and reading time. Based on this result, it appears likely that an experiment comparing high-predictability nouns to low-predictability adjectives would find an even larger difference in reading time than is typically obtained in experiments in which lexical predictability is manipulated.

The major implication for the E-Z Reader model, then, is that additional variance in reading time may be accounted for by taking syntactic category predictability into account, especially for low (lexical) predictability words. It seems likely that most open-class words in printed texts fall toward the low-predictability end of the spectrum (though I know of no data that directly address this point). If this is correct, then syntactic category predictability may turn out to be a rather important factor in accounting for word-to-word variation in reading time.

Table 1. Experiments 1-3: Participant mean lexical decision RT and reading times, by condition (with standard error of the mean).

	Lexical Decision RT (Exps. 1, 2)		Reading Times (Exp. 3)					
	Modifier	Head Noun	Modifier			Head Noun		
Condition			First Fix.	Gaze	Go-Past	First Fix.	Gaze	Go-Past
Adj Noun	602 (20)	597 (19)	248 (6)	280 (9)	308 (12)	275 (6)	300 (6)	329 (10)
Noun Noun	575 (17)	657 (25)	242 (6)	264 (7)	278 (7)	279 (7)	306 (9)	329 (12)
Det Noun		607 (22)						
Num Noun		615 (23)						

Table 2. Experiments 4-5: Participant mean lexical decision RT and reading times, by condition (with standard error of the mean).

	Lexical Decision RT (Exp. 4)	Reading Times (Exp. 5)					
	Adjective	Adjective			Noun		
Condition		First Fix.	Gaze	Go-Past	First Fix.	Gaze	Go-Past
Adv. Adj.	635 (23)	275 (5)	306 (7)	349 (11)	267 (6)	293 (7)	328 (11)
No Adv. Adj.	665 (22)	274 (5)	315 (9)	366 (15)	277 (7)	316 (8)	351 (11)
Adv. Nonword	690 (23)						
No Adv. Nonword	678 (22)						

APPENDIX A

MATERIALS IN EXPERIMENTS 1-3

In Experiment 3, participants read the entire sentence; depending on the experimental condition, they saw either the word before or after the slash. In Experiment 1, the word before or after the slash was the lexical decision target, and appeared in capital letters. In Experiment 2, the noun after the variable word was the lexical decision target, again appearing in capital letters. Note that in Experiment 2 the target noun could also appear immediately after the determiner, or after a series of cardinal numbers, as described in the text.

1. Ralph said that the rusty/wheel axle was made of iron.
2. Eugene found that the quiet/beach area was perfect for relaxation.
3. Leah believed that the higher/office position was much more desirable.
4. Patty saw that the green/fruit tractor was approaching across the field.
5. The administrator agreed that the foreign/history scholar should be asked to leave.
6. Travis suggested that the greasy/burger restaurant would be a good place for lunch.
7. The instructor thought that the large/paper figure could be used for a demonstration.
8. The hotel guests loved that the busy/city scene was visible from the window.
9. Melissa said that the local/radio factory would have to close down.
10. The inspector knew that the modern/window alarm would be expensive.
11. Jerry knew that the lively/animal display would appeal to his kids.

12. Sam claimed that the recent/picnic weather would not last over the weekend.

13. The young girl claimed that the special/rainbow picture was made by her best friend.

14. The supervisor decided that the fancy/porch furniture would no longer be produced.

15. The guide pointed out that the raised/church ceiling was undergoing repairs.

16. Philip recognized that the tiny/lake cottage was in need of renovation.

17. The speaker said that the regular/traffic complaints were driving him crazy.

18. Dr. Thomas guessed that the newest/finger problem was not serious.

19. The officer required that the clean/house uniform be worn to all the meals.

20. Wanda pointed out that the ancient/giraffe cage would not hold the gorilla.

21. The politician promised that the armed/river patrol would soon be replaced.

22. The surgeon suggested that the helpful/stomach procedure might work on this patient.

23. Ralph proposed that the rapid/truck shipment be unloaded as soon as possible.

24. Louise wished that the towering/business hotel was located closer to the water.

25. The janitor believed that the sloppy/sponge bucket was left out overnight.

26. Brenda hoped that the costly/fabric couch would last longer than the vinyl one.

27. The rancher knew that the chubby/family donkey would have to be sold at auction.

28. The lecturer saw that the white/class board hadn't been cleaned over the summer.

29. The leader assumed that the final/group award would go to the girl scout troop.

30. The boys hoped that the strict/school rules would not lead to many detentions.

31. The protestor demanded that the first/panel discussion take place on Monday.

APPENDIX B

MATERIALS IN EXPERIMENT 4

The target word or nonword appeared in caps; the final word of the context fragment appeared only in the adverb conditions.

1. The colony of bats led us to appreciate the very FOREIGN/DOLEIGN
2. The exterior of an old farmhouse can easily hide the very RECENT/WACENT
3. The sun shone, and the small puppy chased the barely FULL/FUTE
4. The dripping water convinced the man to fix the highly MEANINGFUL/NEANARDESH
5. People passing by persuaded the workmen to modify the extremely WIDE/NIRE
6. The new magazines in the library have caused the utterly RELIABLE/REMIADIT
7. Your visiting friend should enjoy the very TOLERABLE/RALORALET
8. The history of cost overruns serves to complicate the absolutely SUCCESSFUL/INAPESSIRE
9. Some recent authors have described the completely LAZY/AMER
10. Migrating geese fly so that they can identify the absolutely IRRATIONAL/INDATACTER
11. A knowledge of classical music must include the very REALISTIC/PROMASTIN
12. Journals now say that the ozone layer rarely receives the very DELICATE/TERICORE
13. The waiters in the restaurant try to consume the extremely STUPID/SPONAD

14. Turning over the rocky soil should be done to remove the highly
OBVIOUS/RAVIRGE

15. The makers of baby food in glass jars also package the highly MODERN/LADERN

16. The new plastic tape will actually fasten the barely AVAILABLE/NORSHELON

17. The fastest vehicles are likely to pass the totally RIDICULOUS/LEPIDOMUSO

18. All the house sparrows tend to make the totally AMAZING/AMIROPE

19. Members of the committee asked the chairman to declare the somewhat
RANDOM/DARMON

20. The crew was ordered to dig the somewhat EXCESSIVE/RESLEVITE

21. After dinner the aunts asked the children to play the rather TIRED/DRIENT

22. Players from opposing teams exchanged the rather EVASIVE/VASIVER

23. Young families who go to the beach prefer the extremely RAPID/PRADI

24. The publisher's most recent book party included the extremely
TASTEFUL/SLATUFEL

25. The company asked the computer technicians to attend the highly
VISIBLE/REVIBEL

26. Each morning the farmer rose early to begin the highly SPECIAL/LASPERC

27. The zoo's prized tigers were trained to perform the completely UNIQUE/QUINAL

28. Some senators went home over the recess to make the completely
FLEXIBLE/FEXILINT

29. The ducks in the campus pond tend to eat the totally SLIMY/SPINT

30. Many of the factory's employees were sent the very DANGEROUS/GADORNESS

31. The full wastebasket was in danger of tipping over and spilling the rather

BIZARRE/RABBANT

32. The country's citizens hoped for a solution that would require the very

CAREFUL/LACERUF

APPENDIX C

MATERIALS IN EXPERIMENT 5

The material that varied between conditions is enclosed in parentheses; the no adverb condition included the word in the first set of parentheses, while the adverb condition included the word in the second set of parentheses.

1. The (busy) manager demanded some (very) recent movies from the distributor.
2. Your (good) friend criticized your (very) tolerable cooking despite the effort.
3. The (film) director showed some (very) realistic events in his latest movie.
4. Her (lazy) husband shattered many (very) delicate plates by accident.
5. His (four) friends turned away many (very) special people from the party.
6. The (auto) mechanic used some (very) flexible plastic to fix the problem.
7. The (math) professor showed your (very) brilliant answer to the class.
8. The (loud) comedian told some (very) tasteful jokes to begin the show.
9. The (modern) architect knew thirty (fairly) careful workers who could do the job.
10. The (lovely) patient received eleven (fairly) meaningful sessions from the therapist.
11. The (county) workers removed twenty (fairly) wide sidewalks over the summer.
12. The (cement) contractor worked on thirty (fairly) modern homes in the subdivision.
13. The (female) agent signed up twelve (fairly) available actors for the audition.
14. The (oldest) surgeon scheduled Pete's (fairly) random operation before lunch.

15. William (nearly) heard Ford's (fairly) successful executives giving away secrets.

16. The (honest) official planned twenty (fairly) rapid trains for next year.

17. Alice (quickly) moved several (totally) full wastebaskets into the hallway.

18. Carla (quickly) arranged Katie's (totally) unique flowers in a bouquet.

19. The (veteran) athlete watched several (totally) lazy swimmers do their workout.

20. The (foreign) engineer made various (totally) irrational decisions on the project.

21. Lauren (hastily) wrote several (totally) excessive scenes into the script.

22. The (skilled) acrobat performed fifteen (totally) amazing stunts during the show.

23. The (company) technician installed Keith's (totally) reliable computer without any problem.

24. Judy (quickly) discovered several (totally) stupid shows that were currently playing.

25. The (annoying) astronomer pointed out Saturn's (slightly) visible rings on the horizon.

26. The (youthful) journalist received numerous (slightly) evasive answers at the conference.

27. The (mountain) guide pointed out numerous (slightly) dangerous trails in the area.

28. The (valuable) babysitter encouraged Arnold's (slightly) tired children to take a nap.

29. The (vigilant) customs agent noticed Daniel's (slightly) foreign accent at the airport.

30. The (humorous) bandleader wore Victor's (slightly) ridiculous costume in the parade.

31. The (youthful) cop noticed Andrew's (slightly) obvious intoxication at the party.

32. The (teething) toddler left numerous (slightly) slimy toys on the floor.

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